68-12 Abramyan, J*; Shaheen, J; University of Michigan - Dearborn; *abramyan@umich.edu*

Pseudogenized amelogenin reveals early tooth loss in the evolution of true toads

Most anurans exhibit some degree of reduction in their dentition ranging from a lack of teeth in the lower jaws of frogs to complete edentulation in the true toads of the family Bufonidae. Tooth loss in vertebrates is unique in not only eliminating an anatomical structure, but also leading to the degeneration of a host of tooth-specific genes. Here we employ amelogenin (*AMEL*) pseudogenization as a tool to characterize the onset of tooth loss in toads. Comparison of *AMEL* from two members of the family Bufonidae: *Rhinella marina* and *Bufo bufo* with nine extant frog species revealed disruptive mutations indicative of *AMEL* inactivation in toads. dN/dS ratios, as a measure for selective pressure, confirmed neutral evolution in toad *AMEL* and purifying selection in frogs. Nonetheless, toad *AMEL* sequences were remarkably similar at 89.13%, with a moderate substitution rate, similar to comparably diverged frogs, while the ancestral branch leading to bufonids where tooth loss occurred exhibited a high number of mutations and tenfold higher substitution rate. Our calculations revealed that toad *AMEL* remained functional for only 1 - 5 million years after toads diverged from frogs ~80-100 million years ago. In conclusion, we found that *AMEL* pseudogenization involved temporary acceleration in substitution rate, rapid accumulation of inactivating mutations, and tooth loss shortly after the divergence of toads from frogs, indicative of early tooth loss in toads being an adaptive evolutionary process.

102-1 Abu-Bader, L*; Summers, AP; Kruppert, S; Donatelli, CM; College of William and Mary, University of Washington Friday Harbor Laboratories; *layannebader@gmail.com*

Vertebral column bending and intervertebral space shape in fishes

The development of a calcified vertebral column is the key distinguishing feature that separates the subphylum vertebrata from other chordates. During its evolution, the bony vertebrae has taken many different shapes and sizes. In mammals, the individual vertebral bodies are completely solid, with soft vertebral disks in between them to cushion the bony structures as they move within the

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body. In fish, the vertebral column is made of hollow vertebral bodies that encase the remnants of the soft notochordal tissue. The faces of fish vertebral bodies are concave, forming an hourglass shaped opening on the inside when sectioned laterally. The size and shape of this intervertebral opening varies greatly among bony fishes and there is little known about how these differences can affect vertebral bending. We wanted to know how the shape and volume of the intervertebral material might be influencing vertebral bending resistance. To answer this question, we performed bending tests using a material testing system on 3 different sets of vertebrae. First, we bent sections of the vertebral column of 5 different species of fish to failure. Then, we 3D-printed physical models of these same species, and tested them at a range of bending angles. Finally, we created and tested idealized models of the vertebrae. Using these data, we found that the relative volume of the intervertebral space relates to bending resistance; we found that bending resistance decreases as the volume of the intervertebral space increases. It is possible to use the relationships found in our data to estimate the bending resistance in a fish vertebrae by simply measuring the intervertebral volume from a CT scan. This has the dual benefit of enabling estimates from fossils and from specimens only available as fixed material.

111-6 Abzhanov, A; Imperial College London, UK; *a.abzhanov@imperial.ac.uk*

The many faces of evolution: heterochronic developmental mechanisms for adaptive radiations

Our planet's biodiversity is the result of countless evolutionary radiations across a wide range of temporal, geographical and taxonomic scales. Adaptive radiation is the extensive and often rapid evolution of morphologically and ecologically diverse species from a single ancestor. It usually implies two coincidental processes: multiplication of species number (species richness) and increased phenotypic disparity (morphological diversification). The exact mechanisms underlying such taxonomic and morphological diversifications are still being explored and described. Some of the most important examples of adaptive radiations representing different vertebrate clades and taxonomic levels are Darwin's finches (Thraupidae), New World leaf nosed bats (Phyllostomidae)

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and crocodilians (Crocodylia). Cranial diversity in vertebrates is a particularly inviting research topic for understanding mechanisms for adaptive radiations as animal heads and faces show many dramatic and unique adaptive features, which reflect their natural history. We aim to reveal molecular mechanisms underlying evolutionary processes that generate such morphological variation. To this purpose, we employ a synergistic combination of geometric morphometrics, comparative molecular embryology and functional experimentation methods to trace cranial evolution in reptiles, birds and mammals, some of the most charismatic animals on our planet. Our research on morphological skull and face diversity in birds, crocodilians and bats is revealing how particular changes in development, such as heterochrony, can produce morphological alterations for natural selection to act upon. We also show that cranial morphological diversification observed in adaptive radiations can be explained by differential growth and underlying dynamic patterns of cell proliferation and differentiation during craniofacial morphogenesis.

70-6 Adams, DA*; Bierlich, KC; Dale, J; Johnston, DW; Goldbogen, JA; Friedlaender, AS; Segre, P; Blob, RW; Price, SA; Clemson University, Duke University, Stanford University, University of California Santa Cruz; *dsadams@g.clemson.edu*

Control surface-body size relationships in baleen whale species

Maneuverability in the marine environment requires a degree of controlled instability. Cetaceans move by dorso-ventral oscillation of their trunk and caudal flukes and have body designs that allow for efficient, stable, and steady swimming. To maneuver during behaviors like prey capture, their control surfaces (i.e. fluke, flipper, dorsal fin) are used to create controlled instabilities. The morphology of cetacean control surfaces is ecologically important as they constrain hydrodynamic performance, and subsequently influence the ability of cetaceans to execute different feeding strategies. To gain insight into evolutionary patterns of morphological variability in whales that use different feeding strategies, and to help understand the hydrodynamics of foraging, we are analyzing control surface morphology across the cetacean phylogeny. Our initial investigations have focused on the relationships amongst control surface size, shape, and body size of

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three mysticete species: humpback, blue, and minke whales. Using high resolution photographs of planiform control surfaces of multiple individuals, we measured characteristics of the fluke, flipper, and caudal peduncle using the MorphoMetriX software package. We regressed these metrics on body length to understand scaling differences amongst species. Preliminary results indicate that the slope and intercept of control surface metrics vary amongst mysticete species, with some control surface metrics showing isometry. Differences in size and shape of control surfaces among these species may suggest they are using these surfaces differently to harness controlled instability and facilitate maneuvers.

S2-2 Adema, CM*; McQuirk, KA; Seppala, O; Castillo, MG; University of New Mexico, Albuquerque, NM, Research Department for Limnology, University of Innsbruck, Mondsee, Austria, New Mexico State University, Las Cruces, NM; *coenadem@unm.edu*

Fielding freshwater snail immunity

Survival in variable natural environments with (a)biotic stressors (including parasites) requires effective immunity, also for snails (Mollusca, Gastropoda). Gaining in-depth understanding of immunology across snail phylogeny is challenged by great diversity of gastropods. Focused lab research, aided by genomics, led to extensive characterization of molecular immunology of the freshwater snail *Biomphalaria glabrata* (family Planorbidae, Hygrophilid snails), vector of *Schistosoma mansoni*, human parasite. Next generation sequencing (NGS) enables immunogenomics, revealing immune gene complements in genomes of other snail species, including Lymnaeidae and Physidae, also families of Hygrophila. The mechanics of snail immune function (mostly studied in vitro, with genetically similar lab snails) can now be interpreted as some combination of specific molecules and pathways for pathogen recognition, signaling, and humoral and cellular effectors, yielding a degree of pathogen-specificity. Accordingly, snail molecular immunology can provide a resource for ecoimmunology to help identify specific immune factors and processes that aid snail survival in the field when faced with various stressors. A cage-study is in progress with different populations of mitogenome haplotype-characterized *Physella acuta* to compare immune

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transcriptomes among lab-maintained and rewilded snails. Already, NGS showed that use of particular immune pathways and effectors varies among individual *Lymnaea stagnalis* snails of mixed genetic background. Such studies may inform field studies of snail vectors of medical relevance and help define the realities of field immunology of snails.

104-8 Adjerid, K*; Mayerl, CJ; Gould, FDH; Edmonds, CE; Steer, KE; Bond, LE; German, RZ; Northeast Ohio Medical University, Rootstown, OH, Rowan University School of Medicine, Stratford, NJ; *kadjerid@neomed.edu*

How do different feeding delivery parameters affect swallowing behavior in infant pigs?

In infant mammals, feeding is a critical neuromotor behavior that involves the rhythmic activity of sucking, and swallowing, a reflexive event triggered by milk accumulation in the valleculae. We asked how these behaviors respond to variation in sensory input through the delivery of milk from an automated milk delivery system as compared with bottle feeding. We varied milk delivery rate (2 - 6 Hz) and aliquot volume (0.2 to 0.6 ml) with several combinations at a constant volume flow rate (VFR) of 1.2 ml/s. We measured suck frequency, swallow bolus size, milk transport time, and swallow frequency in six infant pigs, *Sus scrofa*. We found that all measures were constant across automated milk delivery rates. However, bottle feeding resulted in smaller boluses and lower suck frequencies. While our results on sucking are consistent with previous studies, our constant swallow frequency result differs, likely due to the extreme values used in that study, which did not control for VFR. Smaller boluses in bottle drinking were likely a result of sucking for aliquot acquisition versus the automated feeding where sucking occurs, but doesn't necessarily correspond to aliquot formation. Smaller aliquots produced exclusively from bottle sucking resulted in reduced bolus transit time and swallow frequencies, suggesting that the efficiency of sucking in infants is a rate limiting step in drinking frequency and the formation of large boluses.

100-8 Afseth, C*; Hellmann, J; Anderson, S; Shim, A; Bell, A;

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The transgenerational effects of personally-acquired and socially-acquired predation cues in three-spined sticklebacks (Gasterosteus aculeatus)

There are a variety of mechanisms through which animals are able to learn about environmental stressors without personally experiencing them. One such mechanism is transgenerational plasticity, in which parental experiences can alter offspring phenotype. Another is social learning, the process of individuals modifying their behavior by observing conspecifics. In this study, we investigated the extent to which three-spined stickleback (*Gasterosteus aculeatus*) offspring phenotypes are altered when parents have socially-acquired information about their environment, in the context of paternal predation effects on offspring antipredator behavior. In a full factorial experiment, we independently manipulated whether fathers were exposed to predation risk or if they received social cues of predation risk via their neighbors. Predation risk was simulated through both visual and olfactory exposure to cues. We then generated offspring and assessed larval antipredator behavior as well as shoaling behavior later in life. Larval offspring of fathers that encountered socially-acquired cues of predation froze for less time when chased with a model sculpin compared to the control and compared to offspring of fathers that personally experienced predation cues. In the adult assays, offspring of fathers personally exposed to predation took longer to approach a shoal of conspecifics compared to the control. This suggests that both socially- and personally-acquired information in parents can have consequences for offspring. These findings have implications for our understanding of how information can be transmitted by individuals within social groups and across generations.

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56-8 Agrawal, S*; Anwar, Z; Song, J; Hedrick, T; Luo, H; Tobalske, B; Cheng, B; Penn State, Royal Veterinary College, University of London , University of North Carolina at Chapel Hill, Vanderbilt University, University of Montana; *ska5623@psu.edu*

Functional modeling of hummingbird musculoskeletal system via

optimization-based synthesis of wing skeletal model, motion kinematics and muscle forces

The superior flight agility of hummingbirds is partly enabled by their ability to modulate wing motion via a highly evolved musculoskeletal system, consisting of a tiny, three-link, approximately 7-degee-of-freedom forelimb and attached feathers. However, due to the limitations of *in-vivo* measurement of muscle activity during free flight, it is challenging to gain insights into the physical activity of the musculoskeletal system, and to develop relevant functional model. In this study, we used a novel method to develop functional models of the hummingbird musculoskeletal system solely based on noninvasive intrinsic measurements. Specifically, we synthesized three sources of existing data, including 1) Computational fluid dynamics (CFD) simulation data for estimating forces applied to the wing, 2) Wing skeletal model from ?CT scan, and 3) Skeletal kinematic data from X-ray videos. The synthesis was conducted by using optimization methods to estimate the model parameters of a collection of hypothesized muscle functional models. Based on the identified models, we are able to gain comprehensive understanding of the functions of Pectoralis and Supracoracoideus, the two power muscles that contribute to all degrees of freedom of the lumped wing motion (i.e., stroke, deviation and pitching), along with two other muscle groups that contribute to the wing deviation and pitching. In particular, we gained insights into the physical behavior, e.g., stress & strain profiles, elasticity, and work loops of the two power muscles. In addition, these models also reveal the key design traits of hummingbird musculoskeletal system that should be translated to robotic flight for achieving hummingbird-level agility.

99-5 Aguiñaga, J*; Gomulkiewicz, R; Watts, HE; Washington State University Pullman, WA; *jaguinaga@ucdavis.edu*

Effects of social information and social sampling methods on environmental assessments

Our understanding of social information processing has been limited by the fact that observed behaviors conflate information processing with resulting responses. Here, we develop a mathematical model that isolates how individuals assess their environment separately

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from individual decision-making. We use this model to examine how social information affects environmental assessments and consider the influence of personal and social sampling efforts, social sampling methods, and types of environmental variation. We show that social information use often improves but sometimes impairs environmental assessments and that the magnitude of the effect increases with environmental variation. Furthermore, while there may be different ways to collect a given amount of information from social partners, our analyses suggest these differences have relatively little impact on the accuracy of environmental assessments.

56-1 Ahmed, I*; Faruque, IA; Oklahoma State University,Stillwater; *ishriak.ahmed@okstate.edu*

A high speed visual tracking system for analyzing in-flight insect interactions

Individual insects flying in crowded assemblies perform complex aerial maneuvers by small changes in their wing motions. To understand the individual feedback rules that permit these fast, adaptive behaviors in group flight, a high speed tracking system is needed that is capable of simultaneously tracking both body motions and these more subtle wing motion changes for multiple insects, extending tracking beyond the previous focus on individual insects to multiple insects. In this system, we have extended our capability to track multiple insects using high speed cameras (9000 fps). To improve the biological validity of laboratory experiments, we tested this measurement system with *Apis mellifera* foragers habituated to transit flights through a test chamber. Processing steps consist of data association, hull reconstruction, and segmentation. We compared the automatic tracker to a manual tracker to check its performance. An early analysis of multiple flight trajectories is presented including segmenting the trajectories into behaviors, and system identification prerequisites.

66-5 Aiello, BR*; Sikandar, UB; Minoguchi, H; Kimball, KC; Hamilton, CA; Kawahara, AY; Sponberg, S; Georgia Institute of Technology, University of Idaho, Florida Museum of Natural History; *baiello3@gatech.edu*

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The evolution of wing shape and movement in bombycoid moths reveals two distinct strategies for agile flight

Flapping flight aerodynamics depends both on wing morphology and movement. However, it is unclear how interspecific variation in wing shape and movement, especially prominent in insects, relates to flight strategy. Previously we examined how wing shape evolved across the phylogenetic split between hawkmoths (Sphingidae) and wild silkmoths (Saturniidae), which have divergent life histories, but agile flight behaviors. Integrating these results with kinematics from two exemplar species and a quasi-steady blade element model, we found evidence that two distinct strategies for agile flight evolved between the clades. Hawkmoths evolved forewing shapes favorable for power reduction and use high frequency wing beats to complete rapid maneuvers. Silkmoths evolved forewing shapes favorable for maneuverability and reduce power using slow high-amplitude wing strokes. To examine if inter-clade differences in kinematic parallel wing shape divergence and extend across the phylogeny, we next collected kinematics in 7 additional species from each family to assess inter-clade aerodynamics. With few exceptions, wing strokes are slow (<20Hz) and high amplitude (127±18 deg.) in silkmoths while rapid (25-70Hz) and low amplitude (106±12 deg.) in hawkmoths, suggesting divergence in wing shape and movement is both correlated and widespread across clades. We suggest that, through selection on both wing shape and movement, performance metrics can be decoupled at evolutionary scales. Finally, these results are integrated into a wider analysis of flight dynamics to explore the correlated evolution of neural and mechanical determinants of flight performance in these diverse agile organisms.

65-10 Ajayi, OM*; Oyen, KJ; Benoit, JB; University of Cincinnati, Cincinnati, OH; *ajayiom@mail.uc.edu*

Timing and severity of stressful temperature exposures influence egg development and hatching success in multiple Ixodid ticks

Ticks are blood-feeding arthropods which vector several pathogens that negatively impact the health of humans and livestock and, hence, are among the most costly ectoparasites in the world. Climate change, habitat fragmentation, and host population shifts are some of the factors which influence tick abundance.

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Specifically, extreme temperatures may limit both the geographic distribution and abundance of tick populations. Although several studies have investigated the effects of extreme temperature on mobile life stages of ticks, data on egg thermal tolerances are uncommon. In this study, we measured the influence of cold-shock (-12.5 to -27.5ºC), fluctuating temperatures, cold acclimation (0ºC; then -15 to -27.5ºC), and heat shock (42 to 45ºC) on the eggs of four Ixodid tick species: *Amblyomma maculatum*, *Ixodes scapularis*, *Dermacentor variabilis* and *Rhipicephalus sanguineus*. We exposed the eggs to temperature treatments during both early and late stages (before and after fecal pellet observation) and assessed larval emergence. More larvae hatched from eggs exposed to stressful temperatures during later development stages compared with those exposed in early stages. In addition, we showed that differences in hatching timing and success are significantly dependent on the severity of temperature treatments and vary among tick species. This study provides a baseline for understanding how the timing and severity of extreme temperature events may influence tick egg development and subsequent population dynamics.

72-3 Akanyeti, O*; Fetherstonhaugh, S; Aberystwyth University; *ota1@aber.ac.uk*

Can one control strategy unite all carangiform swimmers?

Undulatory fishes display a wide range of body amplitudes and wavelengths during steady swimming. These kinematics variations can be associated with differences in morphology (e.g. stiff fish bends less) and are considered as fine-tuning to maintain high swimming efficiency. Yet, we still lack a comprehensive theory that brings biomechanics, physiology, kinematics and hydrodynamics together to explain the kinematics diversity. We have recently proposed a method which automatically translates fish movements into mechanical design guidelines that can be used as a resource for future robotics work. Here, we show that the same method can help us perform multi-species comparisons and generate testable biological hypotheses. We analyse the steady swimming kinematics of ten (sub)carangiform swimmers which exhibit vastly different body shapes and flexural stiffness. We discover that, as diverse as these fishes are, one control strategy may unite them all. What separates fishes, however, are the locations where bending moments

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are applied. Once these locations are factored in, we see that the kinematics diversity collapses into single swimming pattern that is governed by a simple equation.

36-4 Alencar, LRV*; Friedman, ST; Wainwright, PC; Price, SA; Clemson University, University of California, Davis; *alencarlrv@gmail.com*

How fishes change their size and how such changes impact clade-level dynamics

Size is one of the most important features of an organism, as it affects many physiological and ecological characters. By varying one or more of the three major size components: maximum body depth, length, and width, fishes have evolved an amazing variety of body shapes, from dorsoventrally flattened batfishes and laterally flattened flatfishes through to more globular pufferfishes and elongate eels. To understand how this diversity has evolved we quantify the relationship between these three size components across 35 orders and 158 families of teleosts. The overall relationship patterns between standard length and depth or width comprise slopes close to one and high R^2 values. However, we also identified shifts in the slope, intercept, and R^2 values across the phylogeny. We also investigated whether these shifts in the relationship between the three size components impact clade-level dynamics. To do this, we gathered information on species richness, diversification rates, and age for each of these clades. We found that clades which deviate from the general teleost patterns are species poor and have lower lineage diversification rates, especially when exploring relationships between body width and standard length. However, the application of resampling strategies is still needed to rule out potential statistical bias regarding poorly sampled clades. Our preliminary results suggest that the relationships between the three size components are conserved across many clades and those clades that evolved altered relationships potentially incurred a macroevolutionary cost, at least when considering higher taxonomic levels.

25-2 Alfieri, F*; Nyakatura, JA; Amson , E; Institut für Biologie, HU, Berlin, Germany; MfN, Leibniz-Institut für Evolutions- und

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Evolution of bone cortical compactness in slow arboreal mammals

Ecological and phenotypical convergences are a main aspect of evolutionary studies. The independent acquisition of slow arboreality in the two lineages of 'tree sloths' has been considered explanatory of their convergent low bone Cortical Compactness (CC). Accordingly, low CC can be expected in other therians with such ecology but this trait was never investigated in other slow arboreal taxa. We investigated humeral and femoral CC in a sample of 47 extinct and extant taxa, informing our statistical analysis with phylogeny. Together with 'tree sloths', other lineages which convergently evolved the slow arboreal lifestyle were included, namely 'Lorisidae', koalas, Palaeopropithecidae and *Megaladapis*. Moreover, closely related taxa with differing lifestyles, as anteaters, armadillos, galagids, wombats, 'indriids', and lemurids and extinct 'ground sloths' were sampled. 'Tree sloths' show the lowest CC in the whole sample and rather low CC was retrieved in palaeopropithecids (mainly *Palaeopropithecus*) and *Megaladapis*. Low CC in 'tree sloths', palaeopropithecids and *Megaladapis* could represent a convergent trait. However, 'Lorisidae' mirror the generalized mammalian condition of high CC. Koalas do not clearly differ from their close relatives (wombats) and unexpectedly yielded discrepant humeral and femoral patterns. Hence, slow arboreality in mammals is not consistently accompanied with low CC and no direct overall relationship between ecology and low CC can be established. All analyzed extinct sloths show high CC, which corroborate the hypothesis according to which the acquisition of low CC is a recent convergence event between the two genera of 'tree sloths'.

16-2 Alfonso, CA*; Moore, IT; Virginia Tech; *calfonsoc@vt.edu*

Male-male coalitions and aggression in two species of manakins

Manakins are neotropical birds with a polygynous mating system where males aggregate in a specific area (lek) to court females, and direct aggressive interactions are rarely seen. As such, manakins are often considered non-territorial. Moreover, in some manakins species, males form coalitions with other males to perform

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coordinated courtship displays. While existing research has explored these social coalitions and cooperative behavior in manakins, the behavioral response to territorial intrusions by novel males is not well understood. To understand territorial behavior in manakins, we challenged territorial males to simulated territorial intrusions. We conducted these challenges in two species on manakins that differ in their social systems. First, we investigated the wire-tailed manakin "*"Pipra filicauda"*", where males perform cooperatively coordinated displays with other males and queue for future territorial positions. Subsequently, we investigated the red-capped manakin "*"Ceratopipra mentalis"*", which has no cooperative behavior, but males can approach other males to share perches and display little aggression. We tested aggression in these two species by introducing a taxidermic mount intruder onto a territorial male and quantifying the individual's behavioral response. While males of both species responded aggressively to the territorial intrusion, we found no significant differences in the aggression scores between the species. We concluded that while manakins' social organization includes a high tolerance to neighbor males, and in some species, males even cooperate, aggression and territoriality are still present, at least in these two species.

8-1 Ali, JR*; Stoddard, MC; Princeton University, NJ; *jali@princeton.edu*

The evolution of face plumage patterns in amazon parrots

Parrots (Psittaciformes) are among the most colorful birds on the planet. Amazon parrots (genus *Amazona*, n = 34 species) are known for their vibrant plumage. While various *Amazona* species share green plumage covering much of the body, their faces are highly variable in terms of palette (the range of colors present) and pattern (the geometry or arrangement of plumage patches). Does face coloration—which is so variable among *Amazona* species but shared by males and females of the same species—aid in species recognition? While plumage color has been shown to function in species recognition, previous work has been limited to relatively small clades. Here, we use techniques that are relatively unexplored in animal coloration to document the natural history of *Amazona* plumage evolution and to test the intriguing possibility that face plumage across the *Amazona* group has evolved to enhance

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species recognition. We collected UV-visible digital photographs of museum specimens and used avian visual modelling to calculate how these colors would stimulate avian retinas. Next, we used kernel-density estimated (KDE) hypervolumes to measure face palette, i.e., color space occupancy. We then applied eigenfaces—a technique used in human face recognition—to measure *Amazona* face pattern. We show that convex hulls—which are traditionally used in animal coloration studies—overestimate color space occupancy and color overlap, relative to KDE hypervolumes. We demonstrate that KDE hypervolumes and eigenfaces are powerful tools for the analysis of plumage color phenotypes. Using our measures of palette and pattern, we provide a comprehensive description of the evolution of *Amazona* face plumage patterns. Finally, we use phylogenetic comparative methods to test whether *Amazona* faces have evolved to be more divergent in sympatry, consistent with a species recognition hypothesis.

S2-3 Allam, B; Stony Brook University; *bassem.allam@stonybrook.edu*
Multi-omic approaches to reveal interactions between the hard clam and its parasite QPX
QPX is a protistan parasite that infects the hard clam, Mercenaria mercenaria, often leading to the development of inflammatory masses (nodules) that result from intensive hemocyte infiltration to the infection site in an attempt to encapsulate and neutralize parasite cells. Inside nodules, active host-pathogen interactions take place leading either to the death of the parasite or invasion of surrounding tissues, infection worsening and in many cases host death. This presentation will summarize our findings on host-parasite interactions using a complementary set of high-throughput genomic, transcriptomic and proteomic methods. Transcriptomic profiling of nodule tissues and parasite cultures allowed the identification of QPX transcripts produced in clams during infection. In parallel, the investigations allowed the identification of host factors and molecular pathways potentially involved in clam response to the infection. Proteomic methods allowed the identification of host plasma factors that recognize and bind parasite cells in vitro. These included prominent pattern recognition receptors (PRR) such as complement c1q-domain containing proteins and lectins. Results further showed that these PRR are induced upon infection. Finally, RADSeq methods contrasting

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allele frequencies between naïve clams and clams that survived QPX epizootics allowed the identification of genetic markers (SNPs) associated with disease resistance. These markers are being validated via selective breeding trials. Altogether, these results provide valuable information on the molecular crosstalk between QPX and its clam host and open the way for "precision breeding" approaches to improve aquaculture production and protect natural resources.

53-2 Allen, JM*; Hodinka, BL; Leonard, KM; Williams, TD; Simon Fraser University; *jmallen@sfu.ca*

Variation in developmental trajectories associated with facultative pre-fledging mass recession in a common songbird

Many avian species display pre-fledging mass recession, whereby nestlings routinely lose a significant fraction of their body mass in the days prior to their first flight. Despite its prevalence, our understanding of the adaptive function and mechanism for this process is far from complete. Previous studies have employed weight treatment experiments to test if nestlings can control pre-fledging mass recession, producing mixed results and suggesting interspecific variation in the mechanism. Furthermore, no study has investigated how this process affects the development of other somatic and physiological traits, and whether this varies by the environmental context. To address this, we tracked the somatic and physiological development of European starlings (*Sturnus vulgaris*) in response to an experimental increase in their mass preceding fledging. We separated four nestlings (n = 97) in each brood (n = 26) into treatment (n = 46) and control (n = 51) groups. Two nestlings were fitted with 4g (5% BM) weighted backpacks at 15 days old, six days before fledging age, with two nestlings receiving no treatment. Weighted nestlings lost significantly more mass than controls, partially compensating for the weight addition by losing 2.4g on average more between ages 15 to 20. Furthermore, weighted nestlings lost significantly more mass than controls only in the days immediately following treatment (i.e. ages 15 - 17), with no significant difference in mass lost between groups in the latter stages of the experiment (i.e. ages 17 - 20). This accelerated mass recession following treatment was associated with increased tarsus growth and reduced wing growth. Together, our data suggest that

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European starlings can facultatively adjust pre-fledging mass recession and that experimentally accelerating this process results in varied developmental trajectories.

26-3 Allen, KN*; Luong, D; Vázquez-Medina, JP; University of California Berkeley; *knallen@berkeley.edu*

Seal endothelial cells mount a rapid and sustained response to hypoxia

Northern elephant seals deplete blood O_2 stores by up to 90% while diving, exposing the endothelial cell layer in the blood vessels to repeated acute O_2 fluctuations. Similar hypoxia/reoxygenation (H/R) events drive pathological oxidant generation, inflammation, and endothelial dysfunction in many terrestrial mammals, including humans. Seals, however, appear to tolerate inflammation and oxidant stress, though the specific mechanisms implicated here remain unclear. We isolated endothelial cells (ECs) from seal and human placental arteries to study the molecular drivers of hypoxia and oxidative stress tolerance in seal blood vessels. ECs from seals proliferate in adherent culture and express canonical EC markers (PECAM-1, VE-cadherin). Additionally, seal ECs respire, respond to mitochondrial uncoupling and inhibition, and generate oxidants after pharmacological activation of NADPH oxidase. Seal ECs rapidly and robustly activate protective pathways during hypoxia. Seal ECs upregulated HIF-1α protein levels within 15 min of exposure to 1% O_2 (68-fold increase over t=0), while human ECs did not match this magnitude until 1 hour. Beyond 1 hour, HIF-1α levels in human ECs declined rapidly (from 73- to 22-fold by 6 hours) while remaining high (52-fold) in seal ECs. In addition, oxidant generation in response to H/R or pharmacological stimulation with menadione increased by 5-fold in human ECs (p=0.027) but was attenuated in seal ECs (2.5-fold, p=0.18). Furthermore, exposure to lipid peroxides increased lipid peroxidation in human but not seal ECs. Together, our data demonstrate that seal ECs mount a rapid, sustained protective response to H/R, that these cells are adapted to cope with oxidants, and that this is an effective model system in which to study hypoxia and oxidative stress tolerance in diving mammals.

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67-3 Allen, JD; William and Mary; *jdallen@wm.edu*
Larval cloning in brittlestars
The recruitment of new individuals into marine habitats is a critical determinant of community structure, yet much of our understanding of the ecology of marine invertebrate embryos and larvae remains rudimentary. One fundamental assumption of most life histories, that one egg yields one offspring, has been demonstrated to be false under a number of conditions and in a number of taxa. In this talk, our understanding of the production of multiple offspring from a single egg, referred to as polyembryony or cloning, will be re-examined for ophiuroid echinoderms. New insights into the mechanisms, induction and frequency of larval cloning will be provided for the brittlestars, in which larval cloning has been described, but few details have been reported. In particular, new data and a new mode of larval cloning will be described for the daisy brittlestar, *Ophiopholis aculeata*. Preliminary data will also be presented on the ecological consequences of cloning for brittlestars, focused on the potential costs of clone production on larval size, development time and survival to metamorphosis.

108-4 Alston, MA*; Kingsolver, JG; Willett, CS; University of North Carolina at Chapel Hill, Chapel Hill, NC; *meggan.alston@unc.edu*
Testing for trans-generational effects of high temperature exposure in Manduca sexta
Understanding how organisms respond to variation in temperature and other environmental conditions is increasingly important in light of global climate change. Thermal plasticity across generations in addition to within-generation plasticity could have measurable impacts on survival and performance of organisms. However, few studies have adequately distinguished between effects due to trans-generational plasticity and selection (differential survival and/or reproduction) which could result in similar patterns. Here we use *Manduca sexta* to evaluate whether thermal conditions experienced by parents during development result in any significant effects (positive or negative) on survival, growth, development rate, and fecundity of offspring. To discriminate between effects due to trans-generational plasticity versus selection, we tracked families across two generations in order to directly compare parent

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performance and fitness to that of their offspring. Larvae in each generation experienced either control conditions or a 24h heat shock. Our initial results suggest that parental thermal conditions did affect offspring development; heat-shocked parent larvae produced offspring that developed faster than offspring of non-heat shocked parents. Further analysis will determine whether this pattern is consistent with trans-generational plasticity - indicated by offspring showing significantly faster development than their parents. Ultimately, this will improve our understanding of how temperature shapes performance and fitness in this system and contribute to the development of an improved framework for predicting the effects of extreme heat events on ectotherms.

71-5 Amplo, HE*; Flammang, BE; Camp, C; Rutgers University-Newark, NJIT, University of Liverpool; *hea7@njit.edu*

Flipping frogfish fins: Using XROMM to study frogfish pectoral fins during locomotion

Frogfishes are capable of three pectoral-based locomotor behaviors: walking, swimming, and jet propulsion. Most fishes have hinge-joint shoulders and small radials in their pectoral fins. Frogfish pectoral fins have three elongated radials (R1, R2, and R3) and the small scapula and coracoid bones fused to the cleithrum form a ball-and-socket joint shoulder. Frogfish are noted to have an extreme range of motion (RoM) around their shoulder joint, including potential pronation during locomotion. But little work has been done to quantify this RoM or test how frogfish use the pectoral skeleton to flip their fins. Manipulations of dissected frogfish suggests that pronation of the radials is occurring when frogfish flip their fins. It is unknown whether R1 pronates over R2 and R3 when transitioning from swimming to walking, or if another mechanism is at play. In this study, we examined the rotation of pectoral R1 and R3 around the ball-and-socket joint during locomotion using X-Ray Reconstruction of Moving Morphology (XROMM), which allows for *in-vivo* analysis of bone motion during a behavior. We hypothesize that R1 pronates over R3 when reorienting the pectoral fin from swimming to walking. Live *Antennarius commerson* were used for XROMM. Biplanar x-ray videos were analyzed in XMALab and digital bone models of the left-side cleithrum and radials from postmortem μ-CT scans were animated with Scientific

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rotoscoping. RoM and rotation data were collected and pronation was defined as R1 distally crossing R3. We found that long axis rotation was present in R3 while positioning and planting the pectoral fin during a fin flip. However, more data is needed to determine if pronation of R1 over R2/R3 occurs along with long-axis rotation. These preliminary results confirm that XROMM can be used to measure *in-vivo* skeletal kinematics of the frogfish pectoral radials and test how they are used during locomotion.

25-4 Amson, E*; Bibi, F; Museum fur Naturkunde - Leibniz-Institut fur Evolutions- und Biodiversitatsforschung, Berlin; *eli.amson@mfn.berlin*

Differing effects of size and lifestyle on bone structure in mammals

The skeleton is involved in most aspects of vertebrate life history. Previous macroevolutionary analyses have shown that structural, historical, and functional factors influence the gross morphology of bone. The inner structure of bone has, however, received comparatively little attention. Here we address this gap in our understanding of vertebrate evolution by quantifying bone structure in appendicular and axial elements (humerus and mid-lumbar vertebra) across therian mammals (placentals + marsupials). Our sampling captures all transitions to aerial, fully aquatic, and subterranean lifestyles in extant mammal clades. We found that mammalian inner bone structure is highly disparate. We show that vertebral structure mostly correlates with body size, but not lifestyle, while the opposite is true for humeral structure. The latter also shows a high degree of convergence among the clades that have acquired specialised lifestyles. Our results suggest that radically different extrinsic constraints can apply to bone structure in different skeletal elements.

BSP-10-5 Anderson, NK*; Schuppe, ER; Gururaja, KV; Hebbar, P; Mangiamele, LA; Cusi Martinez, JC; von May, R; Preininger, D; Fuxjager, MJ; Brown University, Cornell University, Indian Institute of Science, Srishti Institute of Art, Design and Technology, Indian Institute of Science, Smith College, Universidad Nacional Mayor de San Marcos, California State University Channel

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Convergent evolution of an elaborate display behavior in frogs is associated with similar changes to the androgen hormone system

Convergent evolution—or the emergence of similar traits in unrelated lineages—is common in the animal world. Despite many examples of this phenomenon, we lack a strong understanding of whether these repeated evolutionary events are facilitated by similar changes to the animals' underlying physiology. Our study addresses this gap by examining whether the convergence of an elaborate gestural display in frogs, called foot-flagging behavior, is associated with similar changes to androgen receptor (AR) levels in hind limb musculature. We show that repeated evolution of this novel display across the Anuran phylogeny is associated with an increase in the expression of AR mRNA in thigh muscles that actuate the signal. Moreover, this link between behavior and a node within the androgen hormone system evolves in a mosaic fashion, in that its evolutionary path looks different in each clade. Finally, we find that species differences in the complexity of foot-flagging routine are not associated with such variation in thigh muscle AR, at least within a single genus of foot-flagging taxa. Together, our results suggest that androgen-muscle interactions provide a common conduit for convergence in sexual display behavior, but the dynamics of the physiological systems in these independent evolutionary events are variable.

43-7 Angelier, F; Centre d'Etudes Biologiques de Chizé, CNRS, France; *frederic.angelier06@gmail.com*

What happens when the stressor ends? A study of corticosterone in wild Antarctic seabirds

In the current context of increased anthropogenic activities and global disturbance, assessing the impact of stressful events on wild vertebrates has been a major topic in conservation physiology. Ecologist have relied on a wide range of behavioral and physiological measurements to measure individual sensitivity to stress, and among them, the functioning of the HPA axis (and especially the secretion of glucocorticoids in response to stress) has often been considered as one of the most reliable proxy of the stress response. However, very little is known about the duration of this stress response, and more specifically on the dynamics of

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circulating corticosterone levels when the stressor ends. Using Antarctic seabirds as model species and a specific standardized stress protocol, we examined how corticosterone levels increase during a stressor but also how they change when the stressor ends during the reproductive period. After the initial rise in corticosterone levels in response to the stressor, we found that corticosterone levels decrease quickly at the end of the stressor in some individuals while they keep increasing for several minutes in others. In addition to this astonishing variability, we also found that these corticosterone stress responses and recoveries are linked with individual characteristics such as breeding status, personality, or even some proxies of reproductive success. Altogether, these results suggest that all individuals do not equally react to and recover from a stressor. We believe that these results emphasize the importance of considering the overlooked recovery period when focusing on the impact of stressors on wild vertebrates.

70-9 Antoniak, G*; Xargay, E; Barton, K; Popa, B-I; Shorter, KA; University of Michigan, Ann Arbor, CSTAR Pte Ltd, Singapore; *gjantoni@umich.edu*

Estimating whole-body kinematics of swimming bottlenose dolphins

Cetaceans are very efficient swimmers, with estimated propulsive efficiencies that exceed mechanical propellers. However, experiments to verify these efficiencies have been limited because swimming kinematics and kinetics are difficult to measure due to the inherent challenges of the marine environment. Biologging tags are used to measure kinematic data from a single location on the animal, but information about whole-body kinematics and kinetics is limited. To address this issue, we present an approach to estimate sagittal-plane, whole-body kinematics of a bottlenose dolphin (*Tursiops truncatus*) from tag data using machine learning techniques. We segment the dolphin body according to a sagittal-plane hydromechanical model of bottlenose dolphin swimming, with a head, torso, and two caudal peduncle segments, to which a flexible, semi-lunate fluke is attached. The goal is to map the kinematics of the torso segment that can be measured using biologging tags to the joint angles of the model. A Temporal Convolutional Network (TCN) was chosen due to its ability to take into account temporal

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information in a sequence for predictions. To train the TCN, we used synthetic data from the hydromechanical model. Our results show that the TCN was able to learn the mapping from the torso angle to whole-body dynamics (RMSE = 0.097°). When the TCN trained on the synthetic data was then applied to whole-body kinematic data extracted from videos of sagittal-plane swimming, the network made good predictions of the swimming motion, but with higher error (RMSE = 0.376°). This approach will be used to estimate body posture and swimming kinematics of dolphins in both managed and wild settings, greatly expanding our ability to investigate dolphin swimming behavior using biologging tags.

56-6 Anwar, MZ *; Agrawal, S; Cheng, B; Tobalske, BW; Luo, H; Penn State University,State College, PA, University of Montana, Missoula, MT; *mxa1010@psu.edu*

Escape maneuvers in calliope hummingbirds with visual feedback removed at varied timings

In this work, we aim to understand the roles of visual feedback on the flight control and decision making of hummingbirds during escape maneuvers. We conducted experiments on two male Calliope hummingbirds where we removed their visual feedback by turning off the visible lights at various timings during the escape flight, and use infrared lights invisible to the birds for high-speed camera recordings. A nominal escape maneuver without the removal of vision comprises of two phases: a pitch-roll body rotation with backward translation (0-100ms) followed by a rapid pitch-down transition to forward flight. We found that hummingbirds can complete the first phase of the escape in the absence of visual feedback, but immediately terminates the escape and transitioned into hovering flight afterward. Surprisingly, hummingbirds were able to hover without visual feedback, however, assume a more upright body posture than normal hovering along with the tail flared to its maximum extent. With the visual feedback removed at varied timings, it was found that for trials with vison removed during phase I, the time that hummingbirds attaining hover flight remained approximately constant (~200 ms from the onset of the escape), regardless the timings of vision removal. However, for vison removed during phase II, the braking time (e.g., the time from vision-removed to hummingbirds attaining hovering flight) remained

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approximately constant. This result suggests that Phase I of the escape with body pitch-roll body rotation was either a visually open loop or the hummingbirds intentionally chose not to terminate, depending on the amount of the visual delay. For terminating escape flight, the hummingbirds reduced its flapping frequency to approximately 90% of that of hovering (60 Hz).

65-12 Aragon Traverso, JH*; Melian, AD; Sanabria, EA; Quiroga, LB; Espinoza, RE; Instituto de Ciencias Básicas, Facultad de Filosofía Humanidades y Artes, Universidad Nacional de San Juan,, California State University, Northridge, UNSJ, ICB, Unversidad Nacional de Cuyo, Consejo Nacional de Investigaciones Cientificas y Tecnicas, ICB, UNC, CONICET, CSUN; *juan.aragonytraverso.798@my.csun.edu*

Widow Wars: Testing the Mechanisms Underlying Invasion Success of a Globally Invasive Spider

Invasive species pose a threat to global biodiversity by displacing native species from their habitats. Biological invasions can also be facilitated by global warming and urbanization, which can benefit invasives that have higher thermal tolerances or adaptability. The Brown Widow (*Latrodectus geometricus*) is an invasive spider from southern Africa that has displaced native black widow species in urban environments across the globe. We hypothesized that *L. geometricus* outcompetes native congeners because of its greater tolerance to the higher temperatures associated with urban environments in San Juan, Argentina, and Northridge and Palmdale, California, USA. We (1) estimated the relative abundance of native and invasive widows along transects spanning urban to natural environments, and (2) compared the thermal physiologies (critical thermal maximum, CTmax, and climbing performance from 20-40 ° C) of native and the invasive species on both continents. We found that Brown Widows were more abundant in urban and transitional habitats in San Juan and Northridge, CA, yet Western Black Widows (*L. hesperus*) were more abundant in all habitats in Palmdale. There were no differences in CTmax among species from the same locality, although there were differences among locations. Finally, there were no differences in thermal performance among widow species or locations. Our data suggest the invasive success of Brown Widow in urban areas cannot solely be

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attributed to advantages in thermal physiology and future studies should focus on interspecific interactions.

46-1 Arango, BG*; Ensminger, DC; Harfush-Meléndez, M; López-Reyes, EM; Marmolejo-Valencia, JA; Merchant-Larios, H; Crocker, DE; Vázquez-Medina, JP; University of California, Berkeley, Centro Mexicano de la Tortuga, Centro Mexicano de la Tortuga, Universidad Nacional Autónoma de México, Sonoma State University; *bg.arango@berkeley.edu*

Oxidative stress is a potential cost of synchronized nesting aggregations in olive ridley sea turtles

Olive ridley sea turtles, *Lepidochelys olivacea*, exhibit polymorphic nesting behaviors including a mass nesting behavior called arribada, where thousands of turtles nest at once, and solitary nesting. Arribada nesting may provide benefits including mate finding during nearshore aggregations and predator satiation at the time of hatching, but the potential costs of nesting in arribada have not been explored. We collected blood from olive ridley sea turtles after nesting in arribada and solitary. We measured circulating concentrations of hormones (progesterone, estradiol, corticosterone, thyroxine, and triiodothyronine), markers of oxidative damage (4-hydroxynonenal: 4-HNE, malondialdehyde: MDA, protein oxidation: protein carbonyls, and protein nitration: 3-nitrotyrosine), and glucose and lactate. Nesting in arribada was associated with increased levels of progesterone, thyroid hormones, corticosterone, and glucose suggesting increased metabolic activity. Moreover, nesting in arribada was also associated with increased circulating levels of oxidative damage (4-HNE, MDA, and protein carbonyls). These results suggest that nesting in arribada is metabolically more expensive than nesting solitarily and that oxidative damage is a potential cost of such behavior.

BSP-4-8 Arnaout, B*; Lantigua, KE; Mackenzie, EM; McKinnell, IW; Maddin, HC; Carleton University, Ottawa,ON, Canada; *bassel.arnaout@carleton.ca*

Comparative histology of developing sutures in the chicken skull with implications for the homology of the frontal bone

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The study of vertebrate evolution relies heavily on the identification of homologs in different lineages. However, the use of different definitions of homology has led to controversies regarding the identity of certain homologs, and consequently differing proposed evolutionary histories. One such controversy is the identity of the avian frontal bone. Morphologically the bone has been defined as a frontal based on its shape and position in the avian skull. Developmentally, however, it is proposed to be a fused frontoparietal because it develops from two ossification centres with embryonic origins similar to the frontal and parietal of outgroup taxa. To help resolve this controversy we examined the comparative histology of the region between the frontal bone's two ossification centres, plus five known sutures in the developing *Gallus domesticus* skull. We determined that given the absence of the middle vascular layer, which commonly occurs within developing sutures, the gap between the frontal bone's ossification centres is not a suture, implying that the frontal bone is not likely to be a fused frontoparietal. Our result is in congruence with recent comparative anatomical analyses of the skull roof in Archosauria that reject the frontoparietal hypothesis. Moreover, it represents the first histological examination of chicken skull sutures carried out to date.

64-7 Assis, VR*; Titon Jr, B; Gomes, FR; Ward, CK; Mendonça, MT; University of Sao Paulo, Sao Paulo, SP, Auburn University at Montgomery, Montgomery, AL, Auburn University, Auburn, AL; *v.regina.a@gmail.com*

Ectoparasites impact on stress and immune response in Florida invasive cane toads (Rhinella marina)

Previous studies in a variety of vertebrates predict animals facing different arrays of stressors can exhibit an acute increase in circulating plasma glucocorticoid levels and consequent modulation of the immune response. However, studies investigating how the presence of parasites (external and internal) can affect the way toads deal with acute stressors is scarcely explored. In this study, we investigated if the presence of ectoparasites (ticks) might impact the stress biomarkers and the immune response in the Florida invasive cane toads (*Rhinella marina*). We measured the corticosterone (CORT) plasma levels and the neutrophil: lymphocyte

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ratio (NLR), two common stress biomarkers, and the bacterial killing ability (BKA), a common immune protein component, at baseline (field) and after a short-term stressor (24h restraint). Toads with parasites had higher baseline CORT levels, but the restraint effect was the same for all toads: increased CORT, NLR, and BKA. We also found a negative correlation between body index (BI) and CORT only in parasitized toads, indicating that higher levels of baseline CORT may be associated with a higher energy demand due to the ticks, which results in BI reduction. Nonetheless, ticks' presence does not affect how toads respond to an additional stressor, nor the assembly of the immune response. Further studies, including different immune protocols and investigating the presence of endoparasites, might help to understand these relationships better.

36-8 Atake, OJ*; Eames, BF; University of Saskatchewan; *oja039@mail.usask.ca*

Tesseral development provides insights into evolution of mineralization patterns in jawed vertebrates

Jawed vertebrates fall into one of two lineages: chondrichthyans (sharks, skates, and relatives), and osteichthyans (bony fishes and tetrapods). One of the features that make chondrichthyans unique among jawed vertebrates is that their endoskeletal elements are lined with discrete tiles of mineralized tissue called tesserae. Tesserae exhibit a polygonal mineralization pattern which is morphologically different from the compact and trabecular mineralization patterns seen in osteichthyans. Recently, tesserae were shown to also exhibit a trabecular mineralization pattern that is morphologically identical to trabecular mineralization pattern of osteichthyans. The morphological relationship between polygonal and trabecular tesseral mineralization patterns remains only descriptive at this point from adult studies. How tesserae develop during embryogenesis to exhibit either a trabecular or polygonal pattern is unclear. With the trabecular tesseral pattern appearing to be more abundant in the endoskeleton of the adult little skate Leucoraja erinacea, we hypothesize that trabecular tesseral pattern is the primary mineralization pattern during tesseral development. To test this hypothesis, synchrotron radiation micro-CT imaging and histological analyses were used to characterize the development of

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tesserae in several endoskeletal regions of the little skate. Data from these analyses suggest that the trabecular pattern is the primary mineralization pattern of tesserae, which is retained in some endoskeletal regions or developed further to a polygonal pattern in other endoskeletal regions. These preliminary ontogenetic data from tesserae offer some insights into the phylogenetic appearance of trabecular mineralization in jawed vertebrates.

77-8 Atkins, ML*; Dittmar, K; Dick, C; Lutz, HL; Speer, KA; Davis, SR; Aardema, ML; Porter, ML; University of Hawai'i at Mānoa, Honolulu, HI USA, National Science Foundation, Alexandria, VA USA, Western Kentucky University, Bowling Green, KY USA, Field Museum of Natural History, Chicago, IL USA, Smithsonian Institution, Washington, DC USA, American Museum of Natural History, New York, NY USA, Montclair State University, Montclair, NJ USA; *mlatkins@hawaii.edu*

The visual genes associated with eye reduction and loss in bat flies (Streblidae, Nycteribiidae)

Although parasitism is often associated with a reduction in eye structures, the evolutionary processes driving this reduction are not well-known. Bat flies, a group of parasitic species evolved from fully visual, free-living ancestors, are a unique study system to address this due to the varying levels of eye reduction observed throughout the clade, including species with complete eye loss. The variation in bat fly eye micromorphology (0-54 facets) may also reflect microstructural changes associated with low light levels such as rhabdomere rearrangements. In order to investigate changes in the molecular components associated with these anatomical changes, we assembled de novo transcriptomes (8 spp.) and de novo genomes from (5 spp.) from a diversity of bat fly species. These assemblies were annotated for opsin genes, which encode proteins that are responsible for light detection. Thus far, our analyses of transcriptomes reveal that a common dipteran rhodopsin, Rh1, is present in most bat fly species, with the additional Rh6 present in *Basilia* species. Multi-level analysis using both transcriptomes and genomes allows for confirmation of sequences and a more comprehensive understanding of the RNA expression levels contributing to genetic changes. This work aims to elucidate the

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evolutionary trajectories of broader ectoparasite trends in visual system reductions.

87-6 Audino, JAA*; Serb, JM; Marian, JEA; Iowa State University, Department of Ecology, Evolution and Organismal Biology, Iowa, USA, University of São Paulo, Department of Zoology, São Paulo, Brazil; *audino@iastate.edu*

Gazing at origins and losses: the evolution of mantle eyes and eyespots in bivalves (Bivalvia: Pteriomorphia)

Eyes have evolved numerous times with a great diversity of forms, yet little is known about how eye gain and loss is related to photic environment. The pteriomorphian bivalves (e.g., oysters, scallops, and ark clams) display a remarkable range of photoreceptor organs and ecologies, making them a suitable system to investigate the association between eye evolution and ecological shifts. The present phylogenetic framework was based on amino acid sequences from transcriptome datasets and nucleotide sequences of five additional genes. In total, 197 species comprising 22 families from all five pteriomorphian orders were examined, representing the greatest taxonomic sampling to date. Morphological data were acquired for 162 species and lifestyles were compiled from the literature. Photoreceptor organs occur in 11 families and have arisen exclusively in epifaunal lineages, that is, living above the substrate, at least five times independently. Models for trait evolution consistently recovered higher rates of loss over gain. Transitions to crevice-dwelling habit appear associated with convergent gains of eyespots in some epifaunal lineages. Once photoreceptor organs have arisen, multiple losses occurred in lineages that shift to burrowing lifestyles and deep-sea habitats. The observed patterns provide a basis for future investigations focusing on the diversification of photoreception in bivalve molluscs and the potential ecological factors affecting eye evolution.

85-1 Augustine, KE*; Cubillos, CA; Roberts, HE; Sinclair, BJ; Buckley, TR; Manaaki Whenua - Landcare Research, Auckland, New Zealand, Manaaki Whenua - Landcare Research, Auckland, New Zealand and University of Auckland, New Zealand, Western University,

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Evolution and plasticity of thermal performance in 12 New Zealand stick insect species (Phasmatodea)

To better understand how climate change will disturb today's distribution of plants and animals, we can use interspecific studies along with a phylogeny to look at how different thermal preferences and physiological traits have evolved over time. Here we present preliminary findings from 12 species of native New Zealand stick insects (Phasmatodea) that have radiated from tropical ancestors and now span the full latitudinal range of NZ, from the warm, northern subtropics to the cool, southern temperate environments. We find that species from the subtropics have narrower thermal performance curves (TPCs) for feeding rate than species that occur in colder, southern NZ that are freeze tolerant. Using an acclimation treatment, we do not find that many species shift their thermal optimum suggesting that these species do not rely on plasticity to tune to their environment and instead broadened their thermal performance curves when colonizing temperate New Zealand. To further our understanding about the transcriptomic regulation of thermal performance in stick insects, we also present an RNA-seq experiment looking at differential expression in relation to heat stress in one temperature sensitive species *Clitarchus hookeri* that occurs throughout New Zealand. In addition, we propose an experiment using whole genome bisulfite sequencing to examine how DNA methylation and microRNAs (miRNA) change in relation to temperature stress and determine the extent to which thermal performance is controlled by epigenetic mechanisms.

37-7 Austiff, JK; Harvard University; *jkaustiff@g.harvard.edu*

The role of retinoic acid in the development of an unusual tadpole stomach in the Budgett's frog, Lepidobatrachus laevis

Typical frog tadpoles filter feed and lack a digestively active stomach. Only during metamorphosis, do they develop a functional stomach allowing a shift to feeding on larger prey as an adult. The tadpole of *Lepidobatrachus laevis*, however, develops an adult-like stomach during embryogenesis and is capable of feeding on larger prey as a tadpole. Consequently, *L. laevis* does not undergo a significant dietary shift at metamorphosis. Earlier studies of *L.*

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laevis implicate the down regulation of retinoic acid (RA) as a possible mechanism in this novel adaptation. However, preliminary research only describes the gross morphology of tadpole stomachs treated with RA, begging the question what occurs at cellular and genetic levels during stomach development, and if it in fact recapitulates plesiomorphic stomach development. This study compares gut development of *L. laevis* treated with exogenous RA to that of *Xenopus tropicalis* (a model for typical frog development) treated with an RA inhibitor. The goals of this study are to assess if *L. laevis* stomachs treated with RA recapitulate the plesiomorphic stomach morphology and gene expression modeled by untreated *X. tropicalis*, and if *X. tropicalis* treated with an RA inhibitor show development of an adult-like stomach as in *L. laevis* stomachs, and gain insight for the roll of modified RA signaling in stomach evolution. Histological staining is performed to assess the effect of treatments at a cellular level. Transcriptome analysis is performed to assess the effect of treatments at a genetic level. This analysis will provide a greater understanding of the evolution of developmental modules, their role in the diversification of amphibian life histories, and how that diversification enables changes in diet and niche.

81-8 Austin, LE*; Graham, C; Vickaryous, MK; University of Guelph; *lausti01@uoguelph.ca*

Injury-mediated neurogenesis in the brain of the leopard gecko (Eublepharis macularius)

Neurogenesis is the ability to generate new neurons from resident stem/progenitor populations. Although often understood as a routine or homeostatic process, various taxa of teleost fish, salamanders, and lacertid lizards are also capable of replacing neurons lost due to injury - so called reactive neurogenesis. Here, we investigated reactive neurogenesis in postnatal leopard geckos (*Eublepharis macularius*). To initiate reactive neurogenesis, a single dose of the antimetabolite 3-acetylpyridine (3-AP) was administered. Four days following 3-AP administration, there is widespread evidence of cell death and microglia activation within the medial cortex, the lizard homologue of the mammalian hippocampus. As evidenced by reduced expression of the neuronal marker NeuN, 3-AP appears to selectively target mature neurons. Within 30 days following 3AP

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administration, the medial cortex appears to be structurally restored with a pattern of NeuN expression that closely resembles the uninjured brain. Together, these data provide evidence that the capacity for reactive neurogenesis may be more taxonomically widespread among lizards than previously considered.

108-11 Awde, DN*; Teets, NM; University of Kentucky; *davidawde@gmail.com*

Genetic variation in phenotypic plasticity of thermal limits in Drosophila melanogaster

Thermal conditions are an important determinant of performance and species distributions, and the ability to cope with temperature change depends on an organism's genotype, previous exposure to thermal environments, and the combination of these two factors. Here, we use a subset of isogenic lines from the *Drosophila* Genetic Reference Panel (DGRP) to investigate genotype by environment interactions in thermal limits. To test for developmental and adult acclimation, individuals from each DGRP line were kept at standard (25° C), hot (30° C), or cool (18° C) conditions during larval development or as adults, respectively, and we also tested for short-term hardening capacity by rearing flies at standard conditions and subjecting them to an acute hardening treatment immediately before testing. We then measured critical thermal minimum (CT_{min}) and heat knockdown time of these flies using high throughput methods developed by our group. Preliminary results suggest that the adult thermal environment and acute hardening have strong effects on thermal tolerance, while developmental conditions have a weak effect. In ongoing experiments, we are testing these conditions across lines, so that we can quantify genetic variation in thermal acclimation capacity. Results from this study will identify DGRP lines that have particularly plastic or rigid thermal limits in response to their thermal environment. In the future, this information will be used in a genome-wide association study to characterize the genetic architecture underpinning variation in thermal acclimation capacity and to identify the proximate molecular mechanisms that drive this variation.

S8-6 Ayoub, NA*; Friend, K; Hayashi, CY; Opell, BD; Washington and

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Molecular correlates of spider aqueous glue mechanics

The origin of aggregate silk glands and their production of wet adhesive silks is considered a key innovation of the Araneoidea, a superfamily of spiders that build orb-webs and cobwebs. Aggregate glues are humidity responsive biomaterials, but responsiveness varies considerably among araneoid spiders. Despite a growing interest in the biomechanics of aggregate glues, very little is known about their constituent proteins. Here we describe the material behavior and quantitative proteomics of the aggregate glues of two cobweb weaving species, the Western black widow, *Latrodectus hesperus*, and the common house spider, *Parasteatoda tepidariorum*. We identified 47 and 33 aggregate glue proteins for the two species, respectively. These proteins were highly enriched for glycosylation and phosphorylation relative to proteins found in silk fibers, which likely explains aggregate glue stickiness. Black widow aggregate glue droplets were found to be more extensible, and thus tougher, than house spider aggregate glue droplets, although these differences were not significant. The toughness of both species' droplets exceeded those of most orb-web weaving species that have been characterized. House spider droplets were more responsive to humidity changes than black widow droplets. Differences in humidity responsiveness could be explained by the differences in protein sequence, post-translational modifications, or the non-protein components of the glue droplets. The similar material properties may reflect the conserved protein composition of the two species. Future comparisons will determine if differences in material properties between orb-web and cob-web glue mechanics can be explained by differences in their constituent proteins.

107-6 Azzolini, JL*; DeNardo, DF; Arizona State University, Tempe AZ; *jlazzoli@asu.edu*

Dehydrations suppresses digestion-induced thermophyly in Children's pythons, Antaresia childreni

In many reptiles, including pythons, there is an increase in body temperature during digestion. This is a result of both increased metabolism and behavioral thermophyly, presumably to increase

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digestive performance. However, increased body temperature also increases water loss rates, and many reptiles live where water availability in limited for much of the active season. Therefore, we examined whether hydration state influences digestion-associated thermophyly. Using implanted temperature loggers and 25-45C° thermal gradient, we examined the thermal profile of Children's pythons, *Antaresia children*, through two feeding events, one while fully hydrated and the other while dehydrated to an ecologically relevant state. While *A. childreni* showed post-prandial thermophyly regardless of hydration state, dehydrated snakes returned their body temperatures to pre-feeding levels sooner than did hydrated snakes. These results provide early evidence of a physiological conflict between water balance and digestive performance; however, further studies are needed to quantify the digestive impact of reduced thermophyly associated with dehydration.

47-4 Babonis, LS*; Enjolras, C; Foster, BM; Hugosson, F; Ryan, JF; Martindale, MQ; Cornell University and University of Florida/Whitney Lab, University of Florida/Whitney Lab; *babonis@whitney.ufl.edu*

Knockdown of NvSox2 causes a homeotic shift in cell identity in Nematostella vectensis

Sox genes specify cell identity in many animal lineages. The sea anemone *Nematostella vectensis*, has a diverse repertoire of Sox genes, including orthologs of nearly every Sox subgroup found in bilaterian taxa. With few exceptions, the functions of these Sox genes are not known in cnidarians. Using CRISPR/Cas9-mediated genome editing, we show that knockout of NvSox2 causes a homeotic transformation of one type of cnidocyte (stinging cell) into another in *N. vectensis*. In NvSox2 knockout animals, the small penetrant cnidocytes found in the body wall of the polyp (basitrichous isorhizas) were completely transformed into robust spirocytes, an adherent type of cnidocyte. Knockdown of NvSox2 also resulted in downregulation of cnidocyte-specific transcription factor PaxA in the body wall only; large PaxA-expressing basitrichous isorhizas in the tentacles were unaffected in NvSox2 mutant polyps. Our phylogenetic analysis of Sox genes from a broad sample of cnidarian and bilaterian taxa suggests that NvSox2 is a SoxD ortholog. As SoxD genes are known to regulate differentiation

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of neuronal subtypes across bilaterians, our results suggest this homeotic function of SoxD genes may have arisen before cnidarians and bilaterians diverged from their common ancestor. Robust spirocytes are common in many species of sea anemone but have not been reported previously from *N. vectensis*. We suggest the role of NvSox2 in driving transformation of an adherent cnidocyte into a penetrant cnidocyte was a key regulatory change that promoted the evolutionary transition from an attached to a burrowing lifestyle in *N. vectensis*.

103-1 Bagby, MW*; Ross, MA; Giammona, F; Wake Forest University ; *bagbmw17@wfu.edu*

Ancestral state reconstruction of amphibious species within the order cyprinodontiformes

The order Cyprinodontiformes contains a wide variety of ray-finned fish, such as killifish, many of which have been shown to be able to tolerate a wide range of environmental conditions including temperature and salinity. In fact, many of the species within this order have been shown to exhibit terrestrial locomotion. Some species are able to sustain life on land for several months at a time. Others will spend only small portions of their lives on land due to environmental stressors, escaping predators, poor water conditions, etc. Many species are suspected of exhibiting amphibious behavior due to shallow water depths and tidal fluctuations, yet this has often been subject to contention. The exact number of species which exhibit amphibious traits is also up for debate; however, the present study seeks to examine the current background literature on each species within the order Cyprinodontiformes and assign a degree of amphibious-like behavior to each species. Analysis was performed with confirmed and suspected amphibious species based on life history data. Based on this analysis, an ancestral state reconstruction using BayesTraits was conducted to determine the likelihood of amphibiousness in a common ancestor. Phylogenetic analysis and visualization was conducted using FigTree. Preliminary results suggest ~87% likelihood the common ancestor of Fundulidae was non-amphibious, though this figure lowers drastically to 50% when our suspected amphibious species are included in the analysis. Additional data is

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currently being collected to continue reconstructing amphibious behavior throughout order Cyprinodontiformes.

73-9 Bagheri, H*; Huang, Z; Lentink, D; Marvi, H; Arizona State University, Stanford University; *hbagheri@asu.edu*

The role of basilisk lizard toe fringes in effective water running

Passive mechanisms such as toe fringes contribute towards effective locomotion of lizards. The toe fringes of basilisk lizards have been hypothesized to assist their bipedal running on terrestrial and aquatic environments. This study explored how toe fringes affect the water running of basilisk lizards. Specifically, it looked into how the presence and absence of toe fringes contribute towards their kinematics and dynamics when running on water. A hydrodynamic force platform (HFP) setup was designed and developed to directly measure the exerted forces of the lizard's strides (i.e. foot slap, stroke, and recovery) during water running. The insight gained can be channeled to the fabrication and incorporation of passive mechanism in bioinspired amphibious robots for more efficient dynamic walking and running.

87-1 Baker, CM*; Buckman-Young, RS; Giribet, G; Harvard University, Cambridge, MA; *cmbaker6@wisc.edu*

It's the cute ones you have to watch out for: phylotranscriptomic analysis of velvet worms (phylum Onychophora) and the continued recalcitrance of Peripatidae

Velvet worms (Onychophora) are charismatic soil invertebrates known for their status as a "living fossil", their phylogenetic affiliation to arthropods, and their distinctive biogeographic patterns. However, several aspects of their internal phylogenetic relationships remain unresolved, limiting our understanding of the group's evolutionary history, particularly with regard to changes in reproductive mode and dispersal ability. To address these gaps, we used RNA sequencing and phylogenomic analysis of transcriptomes to reconstruct evolutionary relationships and infer divergence times within the phylum. We recovered a fully resolved and well-supported phylogeny for the circum-Antarctic family Peripatopsidae, which retains signals of Gondwanan vicariance and showcases the evolutionary lability of reproductive mode in the family (with at

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least two transitions to oviparity and multiple forms of viviparity). Within the Neotropical clade of Peripatidae, though, we found that amino acid-translated sequence data masked nearly all phylogenetic signal, resulting in highly unstable and poorly supported relationships. Analyses using nucleotide sequence data were able to resolve many more relationships, though we still saw discordant phylogenetic signal between genes, indicative of a rapid, Late Cretaceous-early Paleogene radiation in the group. Finally, we hypothesize that the unique reproductive mode of placentotrophic viviparity within the Neotropical peripatids may have facilitated the multiple inferred instances of over-water dispersal and establishment on oceanic islands.

67-8 Baker, JB*; Saksa, KV; Kashef, NS; Stafford, DM; Sogard, SM; Hamilton, SL; Logan, CA; Moss Landing Marine Laboratories and CSU Monterey Bay, Moss Langing Marine Laboratories, Marine Science Institute UCSC and NMFS South West Fisheries Science Center, Marine Science Institute UCSC and NMFS South West Fisheries Science Center, NMFS South West Fisheries Science Center, Moss Landing Marine Laboratories, CSU Monterey Bay; *jabaker@csumb.edu*

Maternal environment drives larval rockfish gene expression patterns

Global climate change is driving shifts in ocean chemistry, which combined with intensification of coastal upwelling, reduces ocean pH and dissolved oxygen (DO) content in the nearshore habitats of the California Current System. Physiological plasticity, within and across generations, might be especially important for long-lived, late-to-mature species, like rockfishes (genus *Sebastes*), that may be unable to keep pace with climate change via genetic adaptation. Rockfishes exhibit matrotrophic viviparity and may be able to buffer their offspring from environmental stress through early developmental exposure or transgenerational plasticity (non-genetic inheritance of phenotypes). We pre-exposed mother gopher (*S. carnatus*) and blue (*S. mystinus*) rockfish to one of four treatments; 1) ambient conditions, 2) low pH, 3) low DO, or 4) combined low pH/DO stressor during fertilization and gestation, followed by a 5-day larval exposure after birth in either the same or different treatment. We used RNA sequencing to determine how the maternal environment affected larval rockfish gene expression (GE).

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We found that the maternal exposure drove larval GE patterns regardless of sampling time point or treatment. Furthermore, the maternal environment continued to strongly influence larval GE for at least the first five days after birth. These data suggest that rockfish may not be able to buffer their offspring from environmental stressors, highlighting the important role of the maternal environment during gestation.

S12-14 Balakrishnan, CN*; Baldwin, MW; Wirthlin, M; Toda, Y; Manakin, RCN; East Carolina University, Max Planck Institute for Ornithology, Carnegie Mellon University, University of Tokyo; *chrisbala10@gmail.com*

Sexual selection and its impacts on genome evolution: Insights from the Manakin Genomics Research Coordination Network

Sexual selection has long been considered an important driving force underlying evolutionary novelty. In contrast to ecological adaptations, sexually selected traits provide a benefit primarily in the context of securing mates. Although a robust body of theory supports our understanding of sexual selection, little empirical data has been brought to bear regarding how strong sexual selection impacts patterns of genome evolution. A striking example of a clade under strong sexual selection is the neotropical family Pipridae, the manakins. These birds feature acrobatic courtship displays, morphological and endocrine modifications to support these displays and striking plumage colors, each of which varies across the manakin phylogeny. In this study we sequenced and assembled the genomes of five manakin species and compared those genomes to closely related avian outgroups. Using comparative genomic approaches, we find evidence of selection on both protein coding sequences and conserved noncoding elements associated with a dietary shift towards frugivory, sensory perception and muscle performance. Functional testing of taste receptors reveal important changes that occur before the radiation, implicating frugivory as a key factor promoting sexual selection. Taken together our analyses characterize patterns of genomic change preceding and during a radiation under strong sexual selection.

94-10 Balebail, S*; Sisneros, JA; University of

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Washington; *sujayb@uw.edu*

Using finite element analysis to investigate the role of the swim bladder in directional hearing by the plainfin midshipman (Porichthys notatus)

Unlike terrestrial animals, fish determine the direction of sound from acoustic particle motion cues. However, sounds coming from opposite directions generate similar particle motion. Fish possessing gas filled swim bladders are thought to detect sound pressure indirectly via the stimulation of the inner ear otoliths from the sound scattered by the swim bladder. It is believed that pressure detection aids in distinguishing sounds incident from opposite directions. However, few experiments have been conducted to test this hypothesis. Plainfin midshipman have become model organisms to investigate sound source localization because of the innate attraction of females to the advertisement calls produced by type I "singing" males. We are using computerized tomography scans of the inner ear otoliths and the swim bladder in a finite element model to study how the presence of a gas filled swim bladder modifies the motion of the three paired (left and right) otoliths of the saccule, lagena and utricle to low frequency monopole sound sources (within the natural hearing range) in juvenile, adult male (type I), and adult female plainfin midshipman. In our analysis, we varied both the frequency and direction of incident sound relative to the swim bladder. Preliminary investigations indicate that the presence of the swim bladder amplifies the motion of lagenar otoliths in the vertical direction. Since the hair cells corresponding to these otoliths are maximally sensitive to vertical vibrations, the lagena may function as an indirect pressure sensor, detecting sound re-radiated from the swim bladder.

56-7 Baliga, VB*; Dakin, R; Altshuler, DL; University of British Columbia, Carleton University; *vbaliga@zoology.ubc.ca*

The influence of lateral and frontal optic flow on flight control in Anna's hummingbirds

Birds rapidly integrate visual information during flight and recent studies have revealed some of the fundamental algorithms for avian visual guidance. During hovering flight, hummingbirds respond to global visual motion (optic flow) in six major axes with essentially equal strength. In contrast, during forward flight

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hummingbirds respond to vertical but not lateral optic flow. Lateral position during forward flight is primarily controlled by balancing the left/right rate of image expansion. Hummingbirds also have two centers of acute vision (lateral vs. frontal). These findings raise the question of whether regions of the visual field contribute equally to guiding locomotion. To address this question, we measured 3D position and velocity during free flight in a tunnel for seven male Anna's hummingbirds. Across seven experiments, we varied lateral and/or frontal optic flow or rate of image expansion by projecting specific patterns on the tunnel walls. When presented with vertical stripes moving either forward or backward on the sides, birds tended to reduce forward velocity, with forward motion yielding a stronger reduction. By presenting birds with a stationary, looming, or receding spiral in front, we found that forward velocity can be influenced by frontal optic flow, and more strongly by receding stimuli. Frontal expansion patterns had little effect on forward velocity. Moreover, we found that flight altitude was influenced by horizontal upward motion, but only when this motion was presented laterally or both laterally and frontally. Frontal motion alone had little effect on vertical course control. Collectively, these results suggest a relative importance of lateral cues over frontal in controlling both speed and altitude of hummingbird flight.

87-4 Ballesteros, JA*; Sharma, PP; University of Wisconsin-Madison, Madison, WI, ; *ballesterosc@wisc.edu*

On consilience and the phylogeny chelicerate arthropods

Consensus about the phylogenetic relationships of chelicerates has remain elusive despite the growing availability of genomic data. While the monophyly of orders is universally supported, there is much less consensus about how these groups relate to each other. Analyses based on morphological characters are portrayed as supportive for the monophyly of terrestrial arachnids and for a basally branching position of scorpions within Arachnida. By contrast, both of these hypotheses are typically rejected in molecular based phylogenies, including genomic analyses. Even within a specific data class, there is no agreement on the placement of neglected orders such as palpigrades, solifugids, and pseudoscorpions. We therefore sequenced phylogenetically

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significant lineages of Chelicerata using a transcriptomic approach, and thereafter compiled and analyzed a comprehensive dataset of representative chelicerate lineages. In addition, we coded a new morphological character matrix for Chelicerata, with the goal of characterizing nodes with heightening conflict between different data classes. Simultaneous analysis of the two data partitions enabled circumscription of the most recalcitrant parts of the chelicerate tree of life. The resulting tree topology facilitated reconstruction of major events in the evolutionary history of chelicerates, with emphasis on the evolution of respiratory and visual systems.

58-1 Balzer, EW*; Grottoli, A; Broders, H; University of Waterloo; *ebalzer@uwaterloo.ca*

Mass variation pattern differences among temperate hibernating bats

In Northern ecosystems, life history strategies and accompanying animal behaviours occur in the context of extreme annual thermal seasonality. Like many mammals, the behaviour of temperate hibernating bats, such as *Myotis lucifugus* and *Myotis septentrionalis* is influenced by seasonality and intraspecific life history differences. For these species, the imperative to achieve sufficient pre-hibernation fat stores must be balanced with the costs of summer reproductive activity. There is evidence that the phenology and rate of mass change differ within and among these species, but such differences have not been adequately quantified. One way to track reproductive and pre-hibernation behaviours may be body mass, which is affected by reproductive and physiological activity. I therefore performed time series clustering on the mass variation patterns of bats captured between 1999 and 2019 in Eastern Canada to illustrate differences among their behaviour. I predicted that pregnancy in females and spermatogenesis in males would yield notable differentiation among groups during the early summer, but that the shared need to gain mass in fall would lead to less distinct differences. When clustered according to dynamic time warping distance, mass variation patterns were most distinct in the early summer, and least so in the late fall. Sex-specific differences were also most pronounced early in the year. These results demonstrate that disparate reproductive investments are

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detectable in the mass of these species, and that all ages and sexes of bats demonstrate similar mass-sequestration patterns prior to hibernation. The lack of differentiation between juveniles and adults in fall furthermore indicates that some external factor likely limits the rate with which juveniles can gain mass prior to hibernation.

63-10 Bansal, N*; Sit, B; Singh, A; Hegde, T; Dutta, R; Prasad, NG; University of Nebraska-Lincoln, IISER Mohali; *nbansal2@unl.edu*

Mating enhances immune function of Drosophila melanogaster populations against bacterial pathogens

Immunity and reproduction are two important processes that contribute to organismal fitness. Sexual activity has been previously shown to determine the degree to which organisms are able to survive infection. While many studies have demonstrated a trade-off between immune function and reproduction, other studies have found a synergistic relationship between the two fitness determinants. It is also generally hypothesised that the sexes may differ in immunity due to sex-specific costs incurred during reproduction, with males sacrificing immune function to increase their reproductive success. In this study, we tested the effect of immune function on the survival of mated and virgin replicates of a large outbred baseline *D. melanogaster* population that was infected with four different bacterial infections. We found enhanced survival of infection in mated flies relative to virgin flies in response to all four bacterial infections across all replicates. We also found no evidence for sexual dimorphism in this response, as there was no difference between males and females in their ability to survive the imposed bacterial infections. Synergistic interaction between reproduction and immune function may exist if it improves overall individual fitness in populations under selection, and are not necessarily limited by each other due to trade-off over finite resources.

49-10 Baran, NM*; Jeong, H; Merritt, JR; Maney, DL; Yi, SV; Emory University, Georgia Institute of Technology; *nicole.marie.baran@emory.edu*

Novel molecular analysis of inversion polymorphism of ZAL3 in

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white-throated sparrow reveals impacts on body condition and gene expression

Chromosomal polymorphisms such as inversions have been linked to the evolution of phenotypic variation, environmental adaptation, and speciation. Recombination suppression within such polymorphisms leads to genetic divergence between the two chromosome types and can enable the evolution of coadapted alleles. The genome of the white-throated sparrow (*Z. albicolis*) contains two exceptionally large chromosomal polymorphisms. The rearrangement on the 2nd chromosome (ZAL2/2^m) has been the subject of extensive study and is linked to both plumage morph and alternative reproductive strategies. Here, we describe our early investigations of a polymorphism on the 3rd chromosome (ZAL3/3^a). Using whole-genome sequencing data, we estimate that the ZAL3 rearrangement is larger in physical size compared to the ZAL2 rearrangement, capturing nearly 1000 genes, but shows less genetic divergence between the two haplotypes. Fixed differences between the haplotypes are predicted to disrupt the coding sequences of several genes, as well as the regulatory sequences of many more. We analyzed both gene expression and allelic bias in brain, heart, and liver tissues, uncovering evidence of regulatory variation on ZAL3 with probable phenotypic effects. By genotyping hundreds of archived samples, we found that ZAL3^a/3^a is the most common genotype (77% of samples), followed by ZAL3/3^a (21%), and ZAL3/3 (2%). The frequencies of each ZAL3 genotype varied by sex, plumage morph, and year, and ZAL3/3 homozygotes had poorer body condition. These findings provide the first evidence of genetic divergence resulting from the ZAL3 polymorphism and its functional consequences.

84-5 Barbasch, TA*; Branconi, R; Francis, R; Pacaro, M; Srinivasan, M; Jones, GP; Buston, PM; Boston University, James Cook University; *tbarbasc@bu.edu*

Negotiations over offspring care: a test of alternative hypotheses in the clown anemonefish

In species with biparental care, conflict arises over how much each parent provides to their offspring because both benefit from shifting the burden of care to the other. Here, we tested alternative models for how parents negotiate offspring care using a wild population of clownfish (*Amphiprion percula*). Using 60

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breeding groups, we experimentally handicapped parents by fin-clipping the female in 20 groups, the male in 20 groups, and neither parent in 20 groups and measured changes in female, male, and pair combined effort in response to handicapping. First, we found that handicapping resulted in a decrease in the number of eggs laid by fin-clipped females and a decrease in the amount of parental care by fin-clipped males. Second, contrary to predictions, female effort did not change in response to the male being handicapped, or vice versa. Finally, the number of embryos that matured to hatching, an indicator of pair effort, was not influenced by the manipulation, suggesting that although the handicap was effective, clownfish do not face the predicted "cost to conflict" when one parent is handicapped. Together, these results question the generality of current theoretical predictions and expand our understanding of the diverse possible outcomes of parental conflict.

77-7 Barreira, SN*; Nguyen, AD; Moreland, RT; Baxevanis, AD; NHGRI/NIH; *sofia.barreira@nih.gov*

AniProtDB: A collection of metazoan proteomes for comparative studies

Comparative genomic and proteomic analyses have provided keen insights into both the commonalities and differences between metazoan species, advancing our understanding of phylogenetic relationships, the evolution of gene families, and the mechanisms underlying biological diversity. Ultimately, the ability to perform these kinds of analyses rests on having reliable proteomic data from which one can confidently make biological conclusions. However, the quality of publicly available data sets remains highly variable, with most being comprised of raw sequencing reads that need to be processed, assembled, and annotated before meaningful information can be extracted from them. To address the void in the availability of high-quality proteomic data traversing the animal tree, we have implemented a pipeline for generating de novo assemblies based on publicly available data from the NCBI Sequence Read Archive, yielding a comprehensive collection of proteomes from 108 species spanning 21 animal phyla. These proteomes were generated using consistent methodologies, quality control thresholds, and measures of completeness. We have also created the

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Animal Proteome Database (AniProtDB), a resource providing open access to this collection of high-quality proteomes, along with information on predicted proteins and protein domains for each taxonomic classification. A BLAST-based interface also allows users to perform sequence similarity searches against all proteomes generated with this pipeline. This solution vastly increases the utility of these data by removing the barrier to access for research groups who do not have the expertise or resources to generate these data and enables the use of data from non-traditional research organisms that have the potential to address key questions in biomedicine.

89-1 Barts, N*; Nieves, N; Trojan, S; Arias-Rodriguez, L; Kelley, J; Tobler, M; Kansas State University, Washington State University, Universidad Juarez Autonoma de Tabasco, Washington State University; *nickrbarts@gmail.com*

The role of plasticity in facilitating colonization of novel environments

Identifying the mechanisms and traits that allow organisms to colonize and persist under novel environmental conditions remains a key challenge in biology. There are three theoretical mechanisms that facilitate the ability of species to invade and adapt to the presence of novel stressors: 1) organisms may rapidly evolve post-colonization as a result of natural selection acting on pre-existing genetic variation, 2) a trait evolved for one function in the original environment may be co-opted for a new function under novel conditions (exaptation), and 3) a trait adaptive in the original environmental context facilitates persistence in another without changing function (pre-adaptation). Using a comparative transcriptomics approach, we quantified adaptive and maladaptive plasticity to infer the potential roles of pre-adaptation and post-colonization evolution in facilitating colonization of extreme environments rich in hydrogen sulfide (H_2S) by ancestral, sulfide-intolerant species that differ in their colonization success. Expression variation indicated that all species respond plastically respond to H_2S exposure, but in largely unique ways. We also found evidence for adaptive plasticity in all species, regardless of colonization success, but only a few of these genes were shared among successful colonizing species. By far, evidence of

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maladaptive plasticity outnumbered evidence of adaptive plasticity in our dataset. Overall, the findings of this study suggest that pre-adaptation in key pathways may initially facilitate colonization of H2S-rich habitats, but post-colonization evolution, potentially potentiated by maladaptive plasticity, is necessary to persist upon exposure to extreme environmental conditions.

39-3 Bastiaans, D*; Herbst, EC; Scheyer, TM; University of Zurich, Switzerland; *dylan.bastiaans@pim.uzh.ch*

Bringing fossils back to life: 3D cranial reconstructions of the highly flattened remains of Thalattosauriformes

Computer tomography (CT) is a common tool in palaeontology, allowing researchers to revisit old descriptions of problematic taxa in unprecedented detail. However, the nature of fossilisation can decrease the effectiveness of traditional radiological approaches. Here we provide new cranial reconstructions of various thalattosaurs using state-of-art tomographic approaches to accommodate for the specific preservational characteristics of their fossil remains. Thalattosauriformes are secondarily aquatic reptiles from the Triassic. This enigmatic clade is characterized by high morphological disparity, particularly in their body sizes, rostral shapes and dentition types. This has raised numerous questions about their functional ecology and potential competition with more abundant marine reptile clades. In addition, their phylogenetic position remains unclear. We focused on the highly flattened specimens from Monte San Giorgio (Middle Triassic, Switzerland/Italy) and some new and more 3D finds from the Middle and Late Triassic of China and North America. We employed a combination of traditional CT and Computer Laminography (CL) to solve the problem of low-resolution output when scanning large flattened specimens. We then created complete 3D cranial models using segmentation, re-positioning, and retrodeformation. This new approach not only offers detailed morphological information for phylogenetic purposes, but also provides 3D data to be used in quantitative shape analyses and detailed biomechanical studies. In this manner, the functional ecology of thalattosaurs and their position relative to the other marine reptile fauna within the foodweb of the Monte San Giorgio region can be studied.

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30-1 Bauer, CM*; Watts, HE; Swarthmore College, Washington State University; *cbauer1@swarthmore.edu*

Preparation, departure, and flight: review of evidence for corticosterone's roles in avian migration

Corticosterone (CORT) has long been considered an important and necessary hormone for avian migration. Exactly how CORT facilitates migration, however, is under debate. We examined the literature to evaluate three non-mutually exclusive hypotheses for CORT's role in migration: 1) CORT facilitates physiological preparations for migration, 2) CORT stimulates departure from origin or stopover sites, and 3) CORT supports long-distance migratory flight. To test these hypotheses, we analyzed both wild and captive studies, including observational studies and experimental manipulations, that presented data relevant to predictions of each hypothesis. Overall, we found weak support for the hypothesis that CORT helps birds physiologically prepare for migration, and moderate support for the hypothesis that CORT stimulates migratory departure. We were unable to adequately test the hypothesis that CORT helps maintain long-distance flight, as few studies have measured CORT in actively flying birds. We provide recommendations for approaches that could be used in future studies to address gaps in our understanding of CORT's role in migration.

25-7 Baxter, DL*; Tytell, ED; Tufts Univ.; *dana.baxter@tufts.edu*

Diversification of internal vertebral morphology of actinopterygian fishes along the benthic-pelagic habitat axis

Bony fishes live in various marine habitats that can be broadly classified as demersal (contacting the bottom occasionally but also venturing into open water), pelagic (swimming continuously in open water), and benthic (touching the bottom most of the time, interacting with different substrates). Due to these differences, swimming and likely vertebral morphology differ between the habitat parameters. A large contributor to body mechanics is the vertebral column, consisting of hourglass shaped vertebrae with a canal through the middle called the notochordal foramen. Internal morphological features of the vertebrae may contribute to overall body mechanics, but they have rarely been studied. We hypothesize

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that pelagic fish should be stiffer than others due to their more constant open water swimming, and smaller foramina would be more advantageous for this. Thus, we measured the diameters and angles of each vertebral cone, the notochordal foramen diameters, and the centrum lengths for 82 actinopterygian fish species found in various habitats using micro-computed tomography scans from oVert downloaded from Morphosource and OSF databases. These measurements were taken along the length of the body at equidistant points, standardized by the body length of each respective species. To test whether vertebral morphology differed for species in different habitats, controlling for phylogeny, we ran phylogenetic generalized least squares tests. We found that the notochordal foramen diameter and posterior cone angle of the pelagic habitat species were significantly smaller than those in benthic or demersal habitats. This pattern of pelagic fishes having smaller foramen diameters and posterior cone angles may contribute to a stiffer vertebral column that supports their lifestyle of swimming in open water.

S4-10 Beatty, AE*; Ballen, CJ; Driessen , EP; Graze, RM; Schwartz, TS; Auburn University; *aeb0084@auburn.edu*

Skill-building in a molecular biology CURE: A delicate balance of structure and student independence

Recently, the field of biology has recognized the importance of early introduction to authentic research experiences in the classroom (i.e. Course-based Undergraduate Research Experiences; CUREs). While studies focused on introductory-level courses demonstrate the benefits of this teaching methodology on student outcomes, their efficacy in upper-level courses is understudied. Upper-level courses typically possess unique elements when compared to introductory courses including (1) class size, (2) course complexity, (3) student confidence levels, (4) professional applicability of learned skills, and (5) the potential for independence. For instructors, one of the most challenging aspects of upper-level CUREs is balancing *structure* and *independence* to maximize student outcomes. Here, we compare self-reported student outcomes from two sections of an upper-level biology CURE over a period of two years. While both sections focused on molecular biology research, one section was provided a structured skill-

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building section preceding their independent research, while the other was offered immediate independence in developing those skills. Student survey reports of confidence, professional applicability, and CURE structure indicate that the inclusion of skill-building led to more positive impacts than when students had increased independence. We discuss our results in the context of each unique element of upper-level courses, focusing on how a blend of skill-building and independence may affect student outcomes. This work is especially relevant for those who teach upper-level CUREs or train and employ undergraduates to conduct research.

BSP-5-5 Beavers, K*; Meiling, S; MacKnight, N; Dimos, B; Brandt, M; Mydlarz, L; University of Texas at Arlington, University of the Virgin Islands; *kelsey.beavers@uta.edu*

Transcriptome analysis of five coral species infected with Scleractinian Coral Tissue Loss Disease

Despite an increase in severity and prevalence of coral diseases, our knowledge of their pathology, etiology and epizootiology is still limited. One emerging disease in particular, Scleractinian Coral Tissue Loss Disease (SCTLD), affects over 20 species of reef-building coral and some of the most susceptible species have been reduced to less than 3% of their initial population densities in some locations. Understanding how SCTLD manifests at the molecular level and how different species are able to respond is necessary to mitigate further spread and mortality. Five Caribbean coral species, *Orbicella annularis, Colpophyllia natans, Porites astreoides, Pseudodiploria strigosa* and *Montastraea cavernosa* , were exposed to SCTLD and a spectrum of disease severity as measured by lesion growth rate was defined. Post-exposure, transcriptomes were sequenced to identify the gene expression patterns and biological processes that distinguish SCTLD-susceptible species from SCTLD-resistant species. Weighted Gene Correlation Network Analysis was used to find modules of highly correlated genes in each species to identify candidate biomarkers for disease severity. In addition, the presence of significant functional categories within each module was tested using Rank-based Gene Ontology Analysis. This bioinformatic approach allows us to link distinct gene expression patterns to varying degrees of

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disease susceptibility, a crucial first step to enhance our understanding of this emerging disease.

104-9 Beery, SM*; Chubb, E; Olson, R; Montuelle, SJ; Curtis, H; Williams, SH; Ohio University, Ohio University Heritage College of Osteopathic Medicine; *sb633118@ohio.edu*

Does sensation within the oral cavity determine occlusal movement and duration?

During feeding in mammals, the breakdown of food is facilitated by occlusion between upper and lower postcanine teeth. Constant monitoring of bolus positioning and reduction is essential to creating a swallowable bolus and protecting the teeth from damage and excessive wear. Sensory nerves of the oral cavity, including the alveolar and lingual nerves, supplying the teeth and tongue, respectively, play a role in bolus monitoring to adjust movements of the jaw during, particularly the occlusal phase of chewing, when cuspal interactions also assist with guiding movements. Here, we compare the kinematics of occlusion during chewing using XROMM in rabbits (N=3) before and after combined superior and inferior alveolar and lingual nerve blocks. The nerve blocks are hypothesized to reduce the duration of occlusion and to alter the spatial dynamics of the movements of the lower teeth relative to the upper teeth. Occlusion duration (as a % of total cycle duration) increased and was twice as variable after treatment (control: mean = 33.0, CV = 18.7; treatment: mean = 41.3, CV = 34.7; $p < 0.01$). The kinematic measurements of occlusal displacements indicate that movements in the mesio-distal plane are smaller after treatment (control: mean = 1.29, CV = 35.8; treatment: mean = 1.21, CV = 34.8; $p = 0.0026$). Displacements in the buccolingual plane is larger after treatment (control: mean = 2.74, CV = 28.8; treatment: mean = 2.83, CV = 37; $p<0.0001$). Altered occlusal dynamics in association with the nerve block provide further support for the role of oral afferents in facilitating occlusal interactions during chewing.

20-7 Belanger, RM*; Crile, KG; Abdulelah, SA; University of Detroit Mercy; *belangra@udmercy.edu*

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Environmentally relevant atrazine exposure causes chemosensory deficits, DNA damage and changes in cell morphology

Atrazine (ATR) is one of the most commonly used herbicide in the U.S. Midwest in agricultural areas. Excess ATR can enter local aquatic environments through groundwater seepage and runoff, causing ATR concentrations to increase and placing non-target aquatic organisms, like crayfish, at risk of ATR exposure. Concentrations of ATR in local streams and rivers have been shown to reach over 80 ppb (μg/L). We have shown that acute exposures to ATR can cause long-term changes in response to both food and conspecific odors in crayfish. Knowing that ATR causes impairments of olfactory-mediated behaviors, we determined that ATR-exposures cause DNA damage to cells of the lateral antennule, in a dose-dependent manner. Thus, ATR exposure ultimately compromises the chemosensory abilities of crayfish. Currently, we are investigating if the hepatopancreas, which is responsible for filtering and detoxifying the body following xenobiotic exposure, can adequately remove ATR from the body. Understanding the effects of ATR and correlating these with accumulation and recovery from exposure to herbicides like ATR will allow us to assess the long-term effects of ATR on aquatic organisms. Because detoxification of xenobiotics is energetically demanding, responses to and recovery from ATR exposures may subsequently impact growth, development and reproduction.

62-5 Benoit, JB*; Bose, J; Talbott, H; Lewis, DA; Polak, M; University of Cincinnati, Cincinnati, OH; *joshua.benoit@uc.edu*

Resistance to ectoparasitic mites yields metabolic trade-offs in fruit flies

Host fitness is reduced by parasites, and hence parasites often are influential agents of natural selection. Traits that confer parasite resistance typically have significant genetic variation, which may be maintained if host fitness is reduced by resistance when parasites are absent. To test for costs associated with resistance, we examined interactions between parasitic mites, *Gamasodes queeslandicus*, in the host, *Drosophila melanogaster*. Selection for resistance increased the ability of flies to prevent mite infestation. Differential gene expression profiling revealed that ectoparasite resistance altered transcript

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expression patterns associated with metabolic processes. These expression differences were supported by decreased starvation resistance, likely arising from increased utilization of nutrient reserves by selected flies. Behavioral activity of the selected flies was increased during the night, which yielded increased nighttime oxygen consumption. Substantial day and night movement of *G. queeslandicus* mites was noted, suggesting increased resistance could be from increased fly activity during the night when flies would normally be least active. Importantly, flies that were restrained showed no increase in resistance, highlighting that movement is a critical factor in behavioral resistance to the ectoparasitic mite. Our studies provide evidence that ectoparasite resistance imposes costs in the absence of mites, manifested as increased host metabolism and activity at night, leading to decreased starvation resistance.

30-5 Benowitz-Fredericks, ZM*; Lacey, LM; Whelan, S; Will, AP; Hatch, SA; Kitaysky, AS; Bucknell U, Bucknell U, Penn State U, McGill U, U Alaska Fairbanks, Inst. Seabird Res and Cons; *zmbf001@Bucknell.edu*

Telomere length explains interindividual variation in physiological and behavioral responses to experimentally-induced declines in local food availability in free-living seabirds

Release of glucocorticoids is considered a primary mediator of energy reallocation in response to challenges in vertebrates; many studies have measured or manipulated them on acute and chronic time scales to study effects on physiology, behavior, reproduction and survival. Fewer have explored potential sources of variation in the magnitude and consequences of glucocorticoid elevation, but telomere length may help explain interindividual variation in responses to challenges. We assessed the effects of acute reductions in food availability on behavior and physiology of free-living kittiwakes (*Rissa tridactyla*) by withholding a food supplement from incubating males after feeding for ~30 days. We assessed movement behavior for 48hrs pre- and post- withdrawal, and changes in body mass and corticosterone (CORT). We also tested the hypothesis that relative telomere length, a proxy for individual quality, explains variation in response to food withdrawal. Despite uninterrupted ability to forage at sea, birds responded to food

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withdrawal by increasing the number and duration of foraging trips, losing more weight and increasing CORT compared to continuously fed controls. However, overall, birds with longer telomeres made more trips and spent more time off the colony, while experiencing smaller increases in CORT. Longer telomere birds were more likely to fledge a chick among controls, and to return the next year regardless of treatment. This study supports the hypothesis that in this long-lived seabird, individuals with longer telomeres are higher quality, but under challenging conditions, prioritize investment in self over chicks.

4-4 Berberi, I*; Segre, PS; Altshuler, DL; Dakin, R; Carleton University, Stanford University, University of British Columbia; *iliasberberi@gmail.com*

Unpredictable hummingbirds: Flight path entropy is constrained by speed and wing loading

Unpredictable movement can provide an advantage when animals avoid predators and other threats. Previous studies have examined how varying environments can elicit unpredictable movement, but the intrinsic causes of complex, unpredictable behavior are not yet known. We addressed this question by analyzing >200 hours of flight performed by hummingbirds, a group of aerial specialists noted for their extreme agility and escape performance. We used information theory to calculate unpredictability based on the positional entropy of short flight sequences during 30-min and 2-hour trials. We show that a bird's entropy is repeatable, with stable differences among individuals that are negatively correlated with wing loading: birds with lower wing loading are less predictable. Unpredictability is also positively correlated with a bird's overall acceleration and rotational performance, and yet we find that moment-to-moment changes in acceleration and rotational velocities do not directly influence entropy. This indicates that biomechanical performance must share an underlying basis with a bird's ability to combine maneuvers into unpredictable sequences. Contrary to expectations, hummingbirds achieve their highest entropy at relatively slow speeds, pointing to a fundamental trade-off whereby individuals must choose to be either fast or unpredictable.

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53-10 Berger, CA*; Steinberg, DK; Tarrant, AM; Woods Hole Oceanographic Institution, MA and MIT-WHOI Joint Program in Oceanography/Applied Ocean Science & Engineering, Cambridge and Woods Hole, MA, Woods Hole Oceanographic Institution, MA, Virginia Institute of Marine Science, VA; *caberger@mit.edu*

Conserved molecular responses to starvation in two Southern Ocean copepods

Copepods are crustacean zooplankton that collectively form one of the most abundant groups of animals on Earth. In the polar oceans, some copepods store large amounts of lipids, making them a critical food resource for higher trophic levels. In this study, we focus on two dominant Southern Ocean copepods that differ in the chemical makeup of their lipid stores. *Calanoides acutus* is predominantly herbivorous and primarily stores wax esters, while *Calanus propinquus* is more omnivorous and stores triglycerides. Adult females of both species were subject to a shipboard experiment, where they were either fed or starved for 9 days and characterized with RNA-seq. We use these experimental data in conjunction with a phylogenetic gene family-level approach to compare the transcriptomic starvation responses of these species. At a broad level, starved individuals of both species downregulate genes related to lipid metabolism and transport, including hydrolases and lipases that catalyze steps in lipid degradation. By explicitly considering the homologous relationships between genes, we test whether, and to what extent, the starvation response is mediated by the same orthologs and gene families. We characterize a conserved starvation response, which may be shared among diverse pelagic copepods, as well as differences in gene expression underlying the two divergent modes of lipid storage.

59-2 Berlow, M*; Derryberry, E; Wada, H; University of Tennessee, Knoxville, Auburn University; *mae.berlow@gmail.com*

Noise as a potential mechanism underlying the effects of urbanization on the avian gut microbiome

The rapid effects of human land development and urbanization present relatively recent but stark changes in the environment, which can have consequences for wild animals. For example, recent

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work suggests that urbanization affects the composition of animal gut bacteria. One evolutionarily unprecedented consequence of urbanization is noise, and noise pollution is most likely a biologically relevant stressor in urban environments. Noise pollution can interfere with many aspects of an animal's life by changing social behaviours, interfering with foraging and predator identification, and changing stress hormone levels. Sustained increases in stress hormones can have wide ranging physiological repercussions and may change the substrate for intestinal bacteria through alterations in gut physiology such as increased intestinal mobility, permeability, and inflammation, leading to changes in the composition and relative abundances of gut microbiota. We experimentally examine this relationship between noise and the gut microbiome through measurements of stress hormones and feeding behaviour.

31-10 Bernhard, MC*; Hirsch, SE; Perrault, JP; Lasala, JA; Mote Marine Laboratory, Loggerhead Marinelife Center; *mbernhard@mote.org*
Impacts of a geotextile container on loggerhead sea turtle nesting in the Gulf of Mexico
Due to coastal development and sea level rise, sandy beaches in Florida, USA are disappearing due to coastal squeeze. This is a cause for concern for wildlife such as sea turtles, which use the habitat for nesting. Solutions include beach nourishment (sand placement) and beach armoring (stabilization structures), both of which have the potential to impact sea turtle nesting and long-term beach stability. As an alternative to the more traditional hardening structures (such as seawalls), a third option, a geotextile tube (geocore) system can be buried to promote a "natural" dune system. However, research on how these structures may impact sea turtles is scarce. Loggerhead sea turtles (*Caretta caretta*) emerge at night to lay their eggs on the sandy beach. A nesting female can abandon her nesting attempt (i.e., false crawl) due to a variety of factors such as the beach slope, sand quality, or disturbance by human presence, lighting, or obstacles. False crawls can waste precious energy reserves that could be used for reproduction. Once eggs are deposited in the sand, they are at the mercy of the local microhabitat for the duration of their incubation. Thus, beach quality is crucial for the development of

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successful hatchlings. The goal of this study was to investigate how the presence of stabilization structures installed on Casey Key, Florida impacts loggerhead nesting. We aim to compare the nesting success (ratio of nests to false crawls) at a natural control site, a geocore site, and site with a seawall. Furthermore, we will investigate loggerhead hatching and emergence success at each site.

51-4 Berning, DJ*; Powers, AK; Garita-Alvarado, CA; Rodiles-Hernández, R; Gross, JB; Ornelas-García, CP; University of Cincinnati, Department of Biological Sciences, Cincinnati, OH, Harvard Medical School, Department of Genetics, Boston, MA, Universidad Autónoma de Mexico, Instituto de Biología, Ciudad Mexíco, Mexíco, El Colegio de la Frontera Sur; *berninde@gmail.com*

Evolution of craniofacial morphology in a cline of Mesoamerican fishes

Diverse geological and environmental pressures can impact morphological evolution. Yet, it remains unclear how ecological factors affect similar species sharing a trophic niche. Here, we investigate populations of *Bramocharax* and *Astyanax* fishes, two morphs inhabiting lakes in Mexico and Central America. Using geometric morphometric analyses of micro-CT scanned skulls, we found both groups exhibit craniofacial variation along a latitudinal cline of four lake populations. This ecomorphological divergence evolved between both morphs despite their sympatry. Southern Nicaraguan populations demonstrate tooth and cranial differences between the morphs while two northern Mexican populations exhibit similarity in dentition and cranial shape. Southern lake populations are geologically much older, possibly enabling evolution and elaboration of more diverse feeding niches. This resulted in southern *Bramocharax* populations displaying more streamlined cranial structure with longer, more numerous unicuspid maxillary teeth compared to *Astyanax*. Further, northern Mexican populations inhabit geologically younger lakes, showing more similarity in morphology. We propose this may be due to a shorter divergence time compared to the Nicaraguan lakes. Patterns of morphological evolution across all four lakes, however, suggest *Bramocharax* fish evolve similar physiological traits to *Astyanax* via parallel evolution. This work provides an important

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case study for differential effects of geological and ecological pressures on morphological divergence in closely-related animals.

44-4 Bersin, TB*; Cordova, KL; Journey, ML; Beckman, BR; Lema, SC; Cal Poly, San Luis Obispo, NOAA Fisheries, NOAA Fisheries; *tbersin@calpoly.edu*

Fasting inhibits GH stimulation of IGF-1 synthesis pathways in the liver of gopher rockfish (Sebastes carnatus)

Growth hormone (GH) regulates growth in fishes by stimulating liver synthesis of insulin-like growth factor-1 (IGF-1), which then mediates growth-promoting pathways in peripheral tissues. However, under conditions of food limitation, fish with low IGF-1 and slow growth can still exhibit elevated circulating GH, suggesting that nutritional stress may alter liver sensitivity to GH. However, the exact mechanism(s) of this inhibition are not well understood. In this study, we explored how food deprivation affected GH induction of liver IGF-1 production in juvenile gopher rockfish, *Sebastes carnatus*. Fish were either fed at a rate of 9% per g body mass or fasted for 14 d and then given a single injection of either recombinant sea bream GH or saline (control). GH injection increased liver IGF-1 mRNA levels in fed rockfish but did not alter IGF-1 gene expression in fasted rockfish. Fasted fish exhibited lower gene transcript abundance for liver GH receptors and reduced mRNA levels for several intracellular proteins involved in the pathway mediating GH induction of liver IGF-1 synthesis, including janus kinase 2 (JAK2) signal transducer and activator of transcription (STAT5b) and hepatocyte nuclear factor 3β (HNF3β). Protein phosphorylation levels of JAK2 and STAT5b were also lower in fasted fish as compared to fed fish, suggesting fasting reduced activation of the IGF-1 synthesis pathways mediated by these proteins. Overall, these findings indicate that food deprivation downregulates hepatic pathways critical for GH stimulation of IGF-1 production and support liver GH resistance as one mechanism contributing to reduced growth of fish during food deprivation stress.

90-1 Bertram, MG*; Tomkins, P; Saaristo, M; Martin, JM; Michelangeli, M; Tomkins, RB; Wong, BBM; Swedish University of

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Agricultural Sciences, Umeå, Västerbotten, Sweden, Monash University, Melbourne, Victoria, Australia, University of California, Davis, Davis, California, United States, Department of Environment, Land, Water and Planning (DELWP), Melbourne, Victoria, Australia; *michael.bertram@slu.se*

Disruption of male mating strategies in a chemically compromised environment

Pharmaceuticals are accumulating in environments globally. This includes trenbolone, a growth promoter that enters waterways in agricultural run-off. However, whether and how drugs like trenbolone impact complex behaviours in wildlife remain largely unknown. We exposed male guppies (*Poecilia reticulata*) to trenbolone and compared the response of exposed and unexposed males to sequentially presented large and small females. Due to a positive size-fecundity relationship, larger females are generally expected to be preferred by males. While we found no evidence that the size of a previously encountered female affected the amount of mating behaviour performed by males during the second presentation, males from both exposure treatments conducted more frequent courting events towards larger females during both presentations, suggesting an absolute preference for greater female size. Further, across both presentations, trenbolone exposure caused a shift in male mating strategy towards increased sneaking behaviour, although male sequential investment into mating effort was not impacted. Our findings contribute to a growing understanding of impacts of pharmaceuticals on wildlife behaviour.

42-1 Bertucci, EM*; Bae, J; Bock, SL; Hale, MD; Moore, JA; Wilkinson, PM; Rainwater, TR; Bowden, JA; Koal, T; PhamTuan, H; Parrott, BB; U. of Georgia, Augusta U., U. of Virginia, Benedict College, Tom Yawkey Wildlife Center, Clemson U., U. of Florida, Biocrates Life Sciences, Biocrates Life Sciences ; *emily.bertucci@uga.edu*

Intrinsic and extrinsic factors contributing to variation in telomere length in neonatal alligators

Intrinsic and extrinsic factors interact to produce variation in individual life history and aging trajectories. Telomeres are structures at the ends of eukaryotic chromosomes that serve critical roles in maintaining genome integrity. In the absence of

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active maintenance, telomeres shorten with age and serve as a marker of age-related functional declines. Variation in early life telomere length is associated with fitness traits such as reproduction and survival, allowing telomeres to provide insight into the long-term consequences of developmental environments. Here, we assess the influence of extrinsic and intrinsic factors on telomere dynamics in hatchling American alligators (*Alligator mississippiensis*) which were incubated under eight different experimental treatments. We measured telomere length and a panel of eight steroid hormones involved in glucocorticoid signaling and synthesis. We find that both extrinsic and intrinsic factors influence variation in hatchling telomere length. Incubation temperature and exposure to the contaminant DDE interacted to affect telomere length. Clutch was an important driver of variation in both telomere length and body size. Interestingly, body mass was negatively associated with telomere length both across and within clutches. We further examined the potential of glucocorticoid signaling to mediate organismal responses to extrinsic factors and found that contaminant exposure elicits increases in circulating levels of cortisol, which trends negatively, although not significantly, with telomere length. Together, these findings advance our understanding of how environmental factors interact with developing embryos to persistently affect telomere biology in a long-lived species.

25-10 Betterton, LM; Shirk, MT; Pirtle, JM; Rohlf, P; Stover, KK*; WVSOM, Aviagen Turkeys Inc.; *kstover@osteo.wvsom.edu*

Limb bone mineral density and morphology affected by more than just body mass in domestic turkeys

As vertebrates increase in body mass, during growth or across generations, the limb bones supporting their mass must also undergo changes to avoid fracture. Some vertebrates have seen large increases in body mass over relatively short evolutionary time scales, for example, meat producing animals and certain human populations. A recent study showed that heavier domestic turkeys have relatively shorter and more robust hind limb bones than their wild counterparts, however, it is unknown how the bone tissue itself might be changing in response to increased body mass. In this study we examined cortical bone mineral density in the

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humerus, femur and tibiotarsus as well as bone strength and distribution in the tibiotarsus. From ages 10 to 18 weeks, male turkeys were repeatedly CT scanned in vivo (n=100/line). We found that in line A, selected for reproductive traits, bone mineral density increased in all three bones measured as the birds grew ($P<0.05$). However in line B, with no selection for reproductive traits, bone density decreased as body mass increased ($P<0.001$). The polar moment of area in the tibiotarsus, a measure of bending strength, increased during growth in line A ($P<0.0001$) but was not significantly different from zero in Line B ($P=0.2117$). Interestingly forelimb and hind limb bones exhibited similar trends in bone density, even though the forelimbs presumably undergo very little loading in the largely flightless domestic turkeys. Calcium is mobilized from cortical bone during egg laying, which is likely why the reproductive selected line exhibits increased cortical bone density with growth, providing a secondary biomechanical advantage. Our future work will include females of these lines to further evaluate the factors influencing bone density.

S4-4 Bhatti, HA*; Ruopp, R; McPherson, A; Full, RJ; University of California, Berkeley; *haideralibhatti@berkeley.edu*

Early technology-based intervention promotes self-efficacy in a bioinspired design course

Often, undergraduate STEM courses overlook the potentially impactful role of early course experiences on psychosocial variables that affect students' academic achievement, retention, and persistence. In our Bioinspired Design course open to all majors and levels of STEM expertise, we designed a 3D printing activity meant to promote students' academic self-efficacy by leveraging the democratization of invention within the maker movement. We developed this activity based on student requests for an early makerspace experience during pilot versions of the course. Inspired by these requests and utilizing an open-source, 3D printed prosthetic hand designed for children affected by symbrachydactyly, each student in the course (Year 1: n=173; Year 2: n=178) 3D printed a prosthetic finger. Each finger was then used in the collaborative, team-based assembly of all parts of the 3D printed prosthetic hand, resulting in a fully functional final product. Survey data from students showed a widespread unfamiliarity with

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both makerspace activities and 3D printing before engaging in the course activity. After completing the activity, survey data showed students were more comfortable using makerspace equipment, more interested in learning about other makerspace equipment, as well as a general sentiment that 3D printing a prosthetic finger was *not* a technically difficult exercise. Students felt a sense of inclusion and belonging to a technological community. Results support the overarching course objective of integrating bioinspired design with the maker movement to empower all students to be makers, specifically through the utilization of technologies like digital fabrication to build societally-beneficial designs.

66-9 Billah, MA*; Faruque, IA; Oklahoma State University, Stillwater; *arif.billah@okstate.edu*

A model for multi-agent group motion inspired by insect visuomotor feedback

Numerous studies have recorded and modeled the optomotor feedback response of individual insects in corridor-like environments over the last few decades. The question of whether these responses contribute to or inhibit group flight/swarming behaviors has not been equally explored. To consider the problem of how biological agents incorporate visual feedback in multi-agent environments, this study extends a wide-field integration model of insect optic flow sensing and visual feedback in a corridor-like environment to feedback in multi-agent dynamic systems. Theoretical analysis and a robotic experiment are conducted for an individual agent operating in an established group formation of other agents. The results indicate feedback from wide-field integration of optic flow input can help participate in established swarms and demonstrate the importance of relative motion between agents in maintaining the swarm.

40-7 Biondi, AA*; Kellogg, JE; Ruane, S; Amplo, HE; Crawford, CH; Flammang, BE; New Jersey Institute of Technology, Rutgers University; *aab53@njit.edu*

Morphological based relationships of the Molidae family supported by molecular phylogeny and 3D geometric morphometrics

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The Molidae family (Order: Tetraodontiformes) is comprised of 3 genera and 5 species which have record-breaking developmental growth. To analyze the relationships among the Molidae family throughout ontogeny, we created a molecular phylogeny and used 3D geometric morphometrics. We used Mitochondrial D-Loop DNA collected from the GenBank® database. The reconstructed tree shows over 98% nodal support for each species (69 *Masturus lanceolatus*, 46 *Mola alexandrini*, 21 *Mola mola*, 23 *Mola tecta*, 1 *Ranzania laevis*, and 61 pufferfish, (*Tetraodon nigroviridis* as the outgroup) present in this analysis. We collected ontogenetic series of *Mola mola*, *Masturus lanceolatus*, and *Ranzania laevis* from museum collections to investigate the morphological characteristics of each genera throughout development. Using a combination of μCT scanning, PTA staining, gross dissection, and quantitative 3D geometric morphometrics, we have been able to compare three species of molids (one of each genus) lending an ontogenetic perspective to the molecular phylogeny.

67-1 Birch, S*; Plachetzki, D; University of New Hampshire, Durham; *sjb1061@wildcats.unh.edu*

A hierarchy of sensory cues control larval settlement in the actinula larvae of Ectopleura crocea (Hydrozoa)

Community dynamics in benthic marine ecosystems are largely driven by larval settlement, which relies on larvae selecting suitable environments based on the integration of sensory cues. The task of selecting habitable substrates by larvae is crucial for the fitness and success of adult individuals since most sessile stages permanently attach to substrates. The colonial hydrozoan *Ectopleura crocea* is an economically important fouling species in the New England fisheries, however, the sensory cues that determine where larvae settle are poorly understood. Here we examine the settlement response of *E. crocea* actinula larvae by leveraging a factorial larval settlement study that examines the effects of light, chemical, and mechanical (texture) cues together with a developmental transcriptome study investigating sensory gene expression. We found evidence for sensory control over larval settlement with chemical cues having the strongest influence on settlement, followed by mechanical cues with a negative effect on settlement. Photosensory cues influenced settlement in the absence

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of chemical and mechanical cues. Additionally, we found significant differential gene expression across various developmental stages and found that candidate sensory gene sets reach their peak expression just prior to the stage where larvae are competent to settle. Our findings reveal a hierarchy of sensory control over larval settlement in *E. crocea* and demonstrate that actinula have the capacity to integrate sensory information from multiple sensory modalities when making settlement decisions.

46-2 Birrell, JH*; Woods, HA; Univ. Montana; *jackson.birrell@umontana.edu*

Do aquatic insects exploit microclimates of temperature, oxygen, and flow to mitigate low-oxygen availability?

Ectotherms often avoid abiotic stress by moving among microclimates. Such behaviors may allow populations to persist within refugia even when macro-conditions are stressful. Whether aquatic insects exploit locally available microclimates, however, has received little attention. For stream insects, life in water is shaped by the scarcity of oxygen. In principle, behavior may allow insects to mitigate oxygen shortages - by choosing local regions of lower temperature, higher dissolved oxygen, and higher flow velocity in ways that increase ratios of oxygen supply:demand. However, because water has such a high heat capacity and is typically well-mixed, temperature and oxygen are not likely to vary strongly over small spatial scales - although they can vary in some systems due to upwelling groundwater or inputs from other sources. By contrast, flows are highly heterogenous, often ranging from < .05 m/s within the substrate to > 1 m/s in the free-stream environment. Exploiting micro-variation in flow may, therefore, be the most reliably available option for aquatic insects to mitigate oxygen shortages. Here, we examine choice-preferences of giant stonefly nymphs, *Pteronarcys californica*, to experimental gradients in temperature, oxygen, and flow. In alignment with our predictions, *P. californica* nymphs show little ability to exploit laboratory gradients in temperature and oxygen; they made weak choices and only when presented with unrealistically large gradients. Flow-choice experiments are ongoing. We predict that stonefly nymphs will exploit micro-variation in flow much more readily - choosing higher water velocities when temperatures are

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high or when oxygen levels were low. These behaviors may allow stoneflies, and other aquatic nymphs, to survive in streams during bouts of low-oxygen availability, which may increase in frequency under climate change.

75-7 Bishop, PJ*; Falisse, A; De Groote, F; Hutchinson, JR; Royal Veterinary College, UK, KU Leuven, Belgium; *pbishop@rvc.ac.uk*

Dynamic optimization estimation of maximum running speed capacity in bipedal archosaurs

Archosaurs (crocodiles, birds and relatives) have included many locomotor habits throughout their history. They are notable in the repeated evolution of obligate bipedality - rarely achieved by other clades - with birds inheriting their bipedal stance from dinosaurs. Yet, owing to marked anatomical transformations, birds may not be suitable for interpreting locomotor function and evolution in all bipedal archosaur lineages. Computational musculoskeletal models and simulations of extinct species can provide an avenue to exploring these questions, using established biomechanical principles. Here, we used in silico predictive simulations to explore musculoskeletal function and performance using dynamic optimization; under the assumption that a behaviour maximizes some performance objective, this can generate simulations of behaviours de novo. We developed simulations of maximum speed running in the extinct dinosaur *Coelophysis* (~15 kg), as well as a modern ground bird, a tinamou (~600 g). Using a subject-specific musculoskeletal model of the tinamou, combined with a Hill-type muscle model, we generated simulations of walking and running gait that were comparable to prior empirical data, and a maximum speed of 3.45 m/s was predicted. Given that soft tissues are not preserved in the fossil record, we also identified the requirements for a simple muscle model (ignoring force-length-velocity effects) that would permit the same level of performance. We then applied this validated framework to *Coelophysis*, demonstrating that it was capable of speeds >6.5 m/s, consistent with data from fossil footprints. These are the first fully 3-D muscle-driven simulations of locomotion in an extinct dinosaur, and pave the way forward for exploring the evolution of bipedality in Archosauria.

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52-12 Black, CR*; Armbruster, JW; Auburn University, AL; *coriblack@auburn.edu*

Automated landmarking captures complex shapes in armored catfish jaws

Geometric morphometrics has been integral to understanding how form and function have evolved. However, traditional landmarking methods are restrictive, which can be a challenge to capture complex three-dimensional shapes. Automated landmarking can alleviate some of these challenges by placing pseudo-landmarks across an entire surface to capture variation in bones with few homologous regions. The neotropical loricariid catfishes (suckermouth armored catfishes or plecos) have ventrally placed oral jaws that are used to scrape food particles from surfaces. The upper jaw consists of a highly mobile premaxilla that is controlled by the maxillary motion via a unique branch of the adductor mandibulae that rotates the upper jaw around a process of the mesethmoid. The lower jaw is comprised of medially separated mandibles that rotate around the long axis within a shallow socket at the anteroventral articulation of the quadrate, which can be operated separately. Across 1006 species of the Loricariidae, jaw shape is highly variable and structurally complex, ranging from short jaws with less than five teeth to long jaws with over 200 teeth. The resulting differences in key characteristics of the jaws compound the difficulty of assessing homologous locations on the jaws for traditional geometric morphometrics. To test the effectiveness of automated landmarking, we isolated oral jaws from 36 species distributed across the phylogeny of armored catfishes from CT scans obtained from the MorphoSource database. Morphospace and phylomorphospace comparisons suggest that automated landmarking methods are better able to group like shapes compared to traditional methods. Nonetheless, automated methods require similar regions to automatically align models and are more susceptible to flipping shapes, which may cause issues in further shape analyses.

S8-4 Blackledge, TA*; Alicea, A; Onyak, A; Htut, K; Singla, S; Dhinojwala, A; The University of Akron; *blackledge@uakron.edu*

Viscid spider silk shows robust adhesion on varied natural surfaces

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The viscid capture threads produced by most of the world's orb-weaving spiders are both a key innovation in spider diversification and an attractive model for synthetic adhesives. The sticky aggregate silk glue in capture threads maximizes adhesion through a beads-on-a-string morphology that by allows multiple glue droplets to simultaneously resist pull-off. These glue droplets are suspended in a cocktail of low molecular mass compounds (LMMC), which modulates glue viscosity to optimize the contributions of spreading and bulk cohesion to adhesion. Recent research suggests that LMMC mediated variation in viscosity helps to specialize spider species for foraging in different microhabitats by improving adhesion up to 10x at specific humidity. However, most of this research is conducted on smooth, hydrophilic glass. In contrast, orb spiders are largely generalists, capturing insects whose cuticles vary from smooth to rough and hair-covered, and which range from hydrophilic to hydrophobic. Here, we present evidence that aggregate silk glue functions as a remarkably robust adhesive across both varied surface roughness and a broad range of hydrophobicity through small changes in spreading and pull-off behavior. This robust performance is important for the generalist predatory strategy of orb spiders and may reduce the probability of insects evolving cuticular defenses against sticking to spider orb webs.

84-1 Bloch, I*; Troupin , D; Sapir, N; University of Haifa; *itaibloch2@gmail.com*

Do females work harder? Sexual differences in parental care in the Little swift (Apus affinis), a monomorphic species

Differences in parental care in birds have been mostly examined in species characterized by sexual dimorphism, and data is scarce regarding the roles of the two sexes in monomorphic birds. Differences between males and females in parental care may include bird movement, foraging, flight behavior, and food provisioning to the young. In this study, we examined the movement characteristics of the Little Swift (*Apus affinis*), a small (25 g) highly aerial and monomorphic species that breed in colonies. I explored the details of bird movement using an advanced tracking system in the Hula Valley of northeastern Israel and found differences between the sexes in movement and parental behavior during the breeding

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season. Specifically, nest residence time, foraging range, number of visits to the colony during the day, and the times of entry and exit to the colony, as well as nocturnal bird activity, differed between females and males. During the night, more females stayed in the colony and males perform more nocturnal movements. During the day, females flew longer distances and their rate of visitation to the breeding colony was lower than that of males. In addition, the peak activity of the females was in the middle of the day compared to the peak activity of males which occurred in the early morning. Our findings help clarify how sexual monomorphism/ dimorphism influences parental care, including how it may affect movement, foraging and caring for the young during the breeding season. A future study quantifying the distribution of insects in time and space will assist in elucidating whether the two sexes respond differently to the abundance and distribution of insects in space and time.

38-8 Bloom, EJ; California State University, Northridge; *elliott.bloom.30@my.csun.edu*

Ecomorphology of penguins in the genus Spheniscus

The interaction between functional morphology and behavior impact the ecology of organisms. Penguins (Family Spheniscidae) effectively fly underwater using their flippers as wings, a result of the penguin wing stroke being virtually identical to that of a volant bird. Wing and beak morphology are both important determinants of foraging ecology. Wing morphology is strongly correlated with foraging ecology in flying birds and due to the similarity in wing stroke, it is likely that differences in penguin wing morphology select for different foraging strategies as they do in flying birds. Beak morphology and bite force are determinants of prey type and size that can be procured. The Humboldt Penguin (*Spheniscus humboldti*) and the Magellanic Penguin (*S. magellanicus*) breed along the coast of South America. Their breeding ranges are mostly allopatric, but they occur in sympatry on a few islands off the coast of southern Chile. Given that these two species have similar body sizes and share a primary food resource, we explored morphological differences within and between species in allopatry and sympatry to determine whether there is evidence for character displacement. I predict that variations in wing and beak morphology

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will allow these species to co-exist in sympatry via exploiting different resources and thus alleviating competition. Penguins were captured near their nests and measurements included three beak dimensions, bite force, body mass, wingspan, and wing area. I (1) characterized the wing and beak parameters within each of the two penguin species throughout their range and (2) determined if there is evidence for character displacement in their wing and beak morphology in the area of sympatry. Preliminary results indicate there are both inter- and intra-specific morphological differences.

78-5 Bobo, JB*; Vernasco, BJ; Watts, HE; Cornelius, JM; Eastern Michigan University, Washington State University, Oregon State University; *jbobo1@emich.edu*

Social cues advance timing of migratory preparations in a seasonal nomad

One of the most widely recognized natural phenomena are the migrations of billions of animals each year. The timing of migrations is crucial for the fitness of mobile organisms because mistimed migration can lead to a lack of resources or difficult conditions. As a result, much work has been done on better understanding the influence of photoperiod and endogenous rhythms on the timing of migration. However there has been little work focused on the importance of social cues in the fine-tuning of migratory timing. The goal of this study is to determine if birds use social cues from conspecifics to fine-tune their initiation of migratory behavior. Red crossbills (*Loxia curvirostra*) are gregarious, nomadic migrants that specialize on patchily-distributed conifer seeds. Previous studies have described the effects of social cues on physiology and behavior, but no work has yet explored the influence of social cues on migratory processes that are regulated by seasonal mechanisms (i.e., photoperiod). Captive, pre-migratory focal birds were housed in individual cages and one month prior to the normal migratory period we paired birds from 2 of the 3 treatment groups with a neighboring cage containing two stimulus birds. Stimulus birds were either on the same photoperiod as focal birds or had been advanced into migratory condition through photoperiod manipulations. We discuss the changes observed in body condition (i.e., fat, mass, and muscle condition) and activity levels in the three treatment groups and examine

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support for the hypothesis that crossbills are using social cues from conspecifics to fine-tune the timing of migratory behavior.

26-12 Boël , M*; Roussel, D; Voituron, Y; Lyon 1 University - CNRS - UMR 5023, Villeurbanne, France; *melanie.boel@univ-lyon1.fr*

A three-quarter reduction of muscular metabolism in mammals: A universal mitochondrial threshold for reactive oxygen species release?

Until now, the studies focused on mitochondrial ROS production have essentially reported on basal non-phosphorylating and maximal phosphorylating states. Such double assessment is useful to compare species, populations or individuals facing environment variations but does not fully reflect the interplay between oxygen consumption and ROS formation, particularly at intermediate activity levels. ROS generation remains low until a threshold value of mitochondrial activity is reached, at which point this production abruptly increases. On the whole, the variation of mitochondrial thresholds for H2O2 generation is globally unknown in animals. The aim of the present study was to i) evaluate the interplay between mitochondrial respiration and H2O2 release during the transition from basal to maximal phosphorylating states in different mammals' skeletal muscle mitochondria in presence of a mixture of substrates (pyruvate, malate and succinate), ii) estimate the range of variation of the resulting threshold values and iii) assess the allometry of these parameters in mammal species ranging from 5 g to 500 kg. Our results showed a substrate-dependent allometric relationship, with small mammals having higher mitochondrial radical production than larger ones (except for the smallest species, *Mus mattheyi*). Despite these interspecific differences, all species exhibited identical burst of H2O2 release at a low rate of oxidative phosphorylation, essentially once the activity of mitochondrial oxidative phosphorylation reached 26% of the maximal respiration. This identical value in every species studied suggests that the threshold for H2O2 generation is a general characteristic of skeletal muscle mitochondria in mammalian species.

26-1 Bogan, SN*; Strader, ME; Hofmann, GE; University of California, Santa Barbara, Auburn University; *snbogan@ucsb.edu*

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Gene regulatory roles of DNA methylation during transgenerational plasticity in the sea urchin Strongylocentrotus purpuratus

Epigenetic processes have been proposed as a mechanistic basis for transgenerational plasticity (TGP). In the sea urchin *Strongylocentrotus purpuratus*, maternal environments can induce 3-6x greater differential CpG methylation in offspring larvae relative to effects of larval developmental environments, suggesting a role for DNA methylation in TGP. However, negligible overlap has been observed between differentially methylated and differentially expressed genes (Strader et al. 2019, 2020). This prompts the question: What gene regulatory roles does DNA methylation possess during TGP, if any? We quantified DNA methylation and gene expression in *S. purpuratus* larvae exposed to different ecologically relevant conditions during gametogenesis (maternal conditioning) or embryogenesis (developmental conditioning). Using a Bayesian approach, we modeled differential gene expression (DGE), alternative splicing, and transcriptional homeostasis as functions of variation in DNA methylation across distinct genomic features and chromatin accessibility states. In response to maternal conditioning, a positive effect of differential intron methylation on DGE exhibited the highest effect strength and probability relative to other regulatory modes. This effect was significantly stronger for genes with accessible transcription start sites and low transcript abundance. Differential exon methylation induced by maternal conditioning showed a significant but weak relationship with spurious intragenic transcription, revealing a possible role for DNA methylation in preserving transcriptional homeostasis. Our results support functional roles for DNA methylation during TGP and context-dependence in these effects related to genic architecture and chromatin state.

77-2 Boggs, TE*; Gross, JB; University of Cincinnati, Department of Biological Sciences, Cincinnati, OH; *boggste@mail.uc.edu*

Potential genomic loss of hemoglobin genes in the blind Mexican cavefish, Astyanax mexicanus as a consequence of life in hypoxic caves

Gene duplication is considered an essential mechanism of adaptive molecular evolution. One labile region of many gnathostome genomes

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that undergoes changes via duplication is a cluster comprised of *hemoglobin* (*hb*) family members. Gnathostome *globin* genes originated from a single proto-*hb* gene and duplicated individually, or in multiples, to generate expanded *hb* repertoires. Thus, genomic intervals of *hb* genes provide the opportunity to evaluate gene diversification in the context of selective environmental pressures. *Hb* clusters, however, diversify through both gene duplication and loss. Important examples of gene loss have been shown to be preceded by environmental change. Therefore, to determine how an environmental shift can impact a *hb* repertoire, we evaluated the genomic structure of a *hb* cluster in *Astyanax mexicanus*, a species supporting two morphotypes: a surface- and a cave-dwelling form. Prior studies indicated reduced oxygen levels in the caves of the Sierra de El Abra, suggesting that cave-dwelling forms have adapted to low levels of environmental oxygen. Based on public annotations of the genomes of both morphs, cavefish appear to have lost several *hb* family members compared to surface fish. We predicted which family members (or duplicates) were differentially lost in cavefish based on structural and phylogenetic analyses. We presume *hb* gene loss in cavefish is the result of selective pressures maintaining those hemoglobin proteins optimally suited for low oxygen conditions in the cave. This work showcases *hb* clusters as important tools for understanding adaptation to low oxygen in the natural world, and showcases gene loss as an adaptive evolutionary mechanism.

23-6 Bolmin, O*; Alleyne, M; Wissa, AA; University of Illinois at Urbana-Champaign; *obolmin2@illinois.edu*

Mobility power flow: How click beetles transmit and dissipate mechanical power

Click beetles use complex systems of springs and latches to generate extremely high accelerations (from 10^2 m/s^2) and bend their body around a thoracic hinge very rapidly in a "clicking" fashion. When unconstrained, this fast bending motion results in a legless jump. The clicking motion can be divided into three phases: latching, loading, and energy release. In this presentation, we answer the following question: How is power transmitted and dissipated throughout the click beetle's body during the fastest and most dynamic phase, i.e., the energy release phase? We develop

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a novel modeling framework based on impedance and mobility methods to model the power flow in click beetles. The click beetle body is modeled as a global structure with coupled substructures. We consider different levels of fidelity for each body substructure and various connectivity and constraints between the substructures and the substrate. For example, initially, the click beetle prothorax and abdomen are modeled as rigid masses. Then, the body masses are modeled as beam elements to account for strain energy storage. The overall goal of this modeling approach is to determine the power transmitted and dissipated through each substructure. Experimental and analytical methods, such as high-speed x-ray recordings and non-linear system identification models, are combined to uncover the governing physics of the energy release and inform the substructures' design for the mobility power flow approach. The mobility framework developed here aims to understand the energy dissipation strategies click beetles use to mitigate damage during ultra-fast energy release.

16-6 Bolton, P E*; Balakrishnan, CN; Ryder, T B; Dakin, R; Moore, I T; Horton, B M; East Carolina University, Smithsonian Institution, Smithsonian Institution, Virginia Tech, Millersville University; *peri.bolton@gmail.com*

Gene expression in neuroendocrine tissues of a cooperatively lekking bird, the wire-tailed manakin

Testosterone (T) is an important modulator of trade-offs in social traits in vertebrates, where high T is typically associated with increased aggression at the expense of prosocial behaviors such as parental care. In the wire-tailed manakin (*Pipra filicauda*), territorial males participate in cooperative lekking displays with subordinate floater males who generally have lower circulating T. Cooperative behavior positively predicts paternity among territorial males, and ascension of floaters to territorial rank. Recent work has demonstrated that T modulates individual variation in cooperative behavior, with status specific effects. In this study we sought to characterize social status specific gene expression and regulatory networks using RNAseq across steroid responsive tissues in the avian Hypothalamic-Pituitary-Gonadal axis, and the Social Behavior Network of the brain. Across tissues, we identified a 'landscape' of differential expression -

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differences in the numbers of differentially expressed genes. These landscapes varied according to each of the behavioral and hormonal traits measured, showing different tissues have different roles within the SBN and HPG depending on the trait regulated. We also identified tissue and status specific patterns of gene expression using weighted gene co-expression network analysis. We find enrichment for behavioral and neuroendocrine related gene ontology categories, including known key regulators of social behavior such as androgen receptor, and prolactin expression. Our study is the first to use transcriptomics across multiple tissues to address complex social behaviors in a wild animal. Our results are discussed in the context of an integrative understanding of the evolution of androgen mediated phenotypes in birds.

BSP-9-5 Borsuk, AM*; Roddy, AB; Theroux-Rancourt, G; Brodersen, CR; Yale School of the Environment, New Haven CT, Florida International University, Miami FL, University of Natural Resources and Life Sciences, Vienna; *aleca.borsuk@yale.edu*

Structural organization of the spongy mesophyll in laminar leaves with reticulate venation

Plant leaves typically have two layers of photosynthetic tissue, the palisade and spongy mesophyll. While palisade mesophyll consists of tightly packed columnar cells, spongy mesophyll is often treated as a random assemblage of irregularly shaped cells. Here, we characterized the three-dimensional structure of the spongy mesophyll in laminar leaves with reticulate venation in 40 species representing 30 genera. In most species, lobed cells gave rise to an ordered structure with the topological and functional properties of a honeycomb. A subset of species with small cells, high cell packing densities, and closely spaced veins had an irregular morphology associated with high surface-area-to-volume ratios and maximum photosynthetic rates. Morphological variation followed allometric scaling laws with constraints imposed by cell and genome size. Our study suggests that simple biophysical principles may govern the patterning of the spongy mesophyll, providing a platform for spatially explicit analyses of leaf development, physiology, and biomechanics.

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44-1 Bottini, CLJ*; MacDougall-Shackleton, SA; University of Western Ontario, London, Ontario, Canada; *cbottin@uwo.ca*
Can exposure to methylmercury affect songbirds' seasonal response to spring photoperiod?
Birds' seasonal transitions between annual cycle stages are regulated by several interacting hormones inducing physiological changes. In spring, lengthening photoperiod induces the expression of deiodinase enzyme in birds' hypothalamus, transforming the thyroid hormone T4 into T3. In turn, T3 is thought to facilitate the release of gonadotropin-releasing hormones (GnRH) by acting at the median eminence. This activation of the hypothalamic-pituitary-gonad (HPG) axis results in gonad maturation and increases circulating sex steroid hormones. Environmental stressors such as exposure to methylmercury (MeHg) contamination could block deiodinase enzyme actions and lead to inhibition of GnRH synthesis or secretion. Such GnRH disruption could strongly impact avian seasonal timing, physiological adjustment and reproductive output. We experimentally determined if MeHg can affect songbirds' seasonal timing through disruption of endocrine balance during the transition to spring phenotype. We captured male song sparrows (Melospiza melodia) and exposed them to an environmentally relevant dose of MeHg for 90 days before photostimulation, and kept them for post-exposure observations for 23 days. Preliminary results indicate that testis volume (measured post-mortem) was not affected by MeHg exposure. We will present results of thyroid hormones and testosterone levels measured throughout this experiment.

69-2 Boudina, M; Gosselin, FP*; Etienne, S; Polytechnique Montreal, Montreal, Quebec, Canada; *frederick.gosselin@polymtl.ca*
Soft corals vibrating under flow to improve food capture?
Sea plume *Antillogorgia bipinnata* is a soft coral species endemic to the Caribbean Sea, which forms arborescent colonies. On the sea floor, a whole colony of *A. bipinnata* sways back and forth at the low frequency of surface wave action, while its branches exhibit a peculiar motion vibrating at high frequency transverse to the flow. In this presentation, we investigate the nature of these unreported high frequency vibrations and hypothesise on their biological implication with regards to food interception. We use computational fluid dynamics to simulate the particle interception of fixed

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cylinders and spring-mounted cylinders. We find that vibrating cylinders can capture up to 40% more particles than fixed ones when the frequency of the vortices shed in the wake of the cylinder matches with the natural frequency of the spring mounted cylinder. Whereas engineers have developed numerous inventions to prevent chimney stacks, risers, and other structures from vibrating due to vortex shedding; our results indicate that soft corals potentially benefit from this same phenomenon. Vortex-induced vibrations allow coral to sweep more water and possibly capture more food particles. Our theoretical results open the door for field and lab experiments for validation, and they provide another example of how natural structures differ from engineer-made ones.

29-8 Bouguerche, C*; Tazerouti , F; Delphine, G; Justine, JL; Université des Sciences et de la Technologie Houari Boumediene, Faculté des Sciences Biologiques, Laboratoire de Biodiversité et Environnement: Interactions - Génomes, Alger, Algérie, Service de Systématique Moléculaire, Muséum National d'Histoire Naturelle, Paris, France, Institut Systématique Évolution Biodiversité, Muséum National d'Histoire Naturelle, Paris, France; *chahinezbouguerche@gmail.com*

No vagina, one vagina, or multiple vaginae? An integrative study of Pseudaxine trachuri (Monogenea, Gastrocotylidae) leads to a better understanding of the systematics of Pseudaxine and related genera

The presence/absence and number of vaginae is essential for the systematics of the Monogenea. Two genera share similar morphology and anatomy but are distinguished by this character: *Pseudaxine* Parona & Perugia, 1890 has no vagina, *Pseudaxinoides* Lebedev, 1968 has multiple vaginae. During a study of *Pseudaxine trachuri* Parona & Perugia 1890, we found specimens with structures resembling multiple vaginae; compared them with specimens without vaginae in terms of both morphology and molecular, and found that they belonged to the same species. We investigated its male copulatory organ and found that it is armed with a single circle of 12 hooks and a central stylet which is probably involved in traumatic insemination. We redescribed *Pseudaxine trachuri* based on newly collected specimens from off Algeria and Museum specimens from off France. Specimens

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from the type-host, *Trachurus trachurus*, were found to be similar, for molecular sequences and morphology to those found on *Boops boops*. We confirm that *B. boops* is a host of this parasite. We consider that *Pseudaxinoides* was erected on the basis of an erroneous interpretation of structures which are not vaginae and propose the transfer of most of its species to *Pseudaxine*.

33-3 Bove, CB*; Davies, SW; Ries, JB; Umbanhowar, J; Castillo, KD; UNC Chapel Hill and Boston University, Boston University, Northeastern University, UNC Chapel Hill; *colleenbove@gmail.com*
Physiological and transcriptomic responses of Caribbean corals under global change
Continued ocean acidification and warming is a major concern for marine organisms, especially for reef-building corals that rely on their symbiotic relationship with algae, which is highly susceptible to perturbation. Coral physiological responses to global change stressors, at the individual and species levels, will ultimately determine the future of tropical reefs. Here, we investigated the combined effects of chronic acidification (280�'3300 μatm) and warming (28, 31 ° C) (95 days) on the physiological responses of three species of coral hosts and their algal symbionts (*Siderastrea siderea, Pseudodiploria strigosa, Porites astreoides*) from the Belize Mesoamerican Barrier Reef System. To explore the molecular underpinnings of these responses, gene expression of *S. siderea* was profiled. Warming more negatively impacted *S. siderea* host physiology, while symbiont physiology declined under acidification. Preliminary gene expression analyses suggest transcriptome resilience to stressors. Warming negatively impacted the majority of *P. strigosa* host and symbiont traits, while host traits and chlorophyll a concentrations in *P. astreoides* were negatively affected by increasing acidification. Principal component analyses revealed that differences in overall coral physiology of all three species were affected by ocean acidification, while warming only impacted *P. strigosa*. These results demonstrate that while ocean warming is a severe acute stressor that will have dire consequences for coral reefs globally, chronic exposure to acidification may be impacting coral physiology to a greater extent than previously assumed. Understanding

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variation in responses is critical to predicting the future of Caribbean reefs as global change unfolds.

34-6 Bow, HF*; Campbell, TM; Gonzales, ES; Michels, LG; Schwartz, SR; Liwanag, HEM; Strand, CR; Cal Poly State U; *cstrand@calpoly.edu*

All in? No effect of meal size on postprandial metabolic rates in Children's pythons

The postprandial increase in metabolism is well documented but can be highly variable between and within species depending on many factors. Larger meals typically cause a larger increase in metabolism. To further investigate this process, we studied the postprandial change in metabolic rate in Children's pythons, *Antaresia childrenii*. We used closed-system respirometry to measure standard metabolic rate (SMR) as mass-specific VO2 (mL hr^{-1} g^{-1}) at 29° C in fasted snakes (n=14) and following feeding of a rodent meal that was 10% or 25% body weight (n=7/group). Measurements were taken 1-3 days before and 0.5, 1, 2, 4, 6, 10, and 14 days post-feeding. Unexpectedly, SMR after feeding was not significantly different between the two meal sizes. Collectively, SMR rapidly increased within 0.5 days after feeding, peaked at one day post-feeding, slowly decreased, and was not significantly different from baseline by 10 days post-feeding. The mean maximum postprandial response was a 4-fold increase in SMR. Animals that feed infrequently tend to have a higher metabolic response to feeding than animals that feed more frequently, presumably due in part to mobilization of energy to grow the organs necessary for digestion and absorption of the meal. While our snakes were fasted for 2.5 weeks prior to the experiment, perhaps the duration of the fast was not sufficient to induce atrophy of the GI tract, thus less energy was required to mobilize the GI tract, even for a larger meal. Alternatively, it may be that these snakes expend energy to a similar extent, regardless of meal size. Future work will examine the fuel source (i.e., RER) associated with the postprandial response in this species.

108-9 Box, ICH*; Marshall, KE; University of British Columbia, Department of Zoology, Vancouver, BC; *box@zoology.ubc.ca*

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Ice-binding proteins and freeze tolerance in the bay mussel (Mytilus trossulus)

Many intertidal invertebrates in temperate regions, including the bay mussel (*Mytilus trossulus*) experience freezing temperatures during low tide in the winter. While *M. trossulus* can tolerate freezing of body fluids throughout the year, individuals collected in the winter and higher in the intertidal zone can survive lower temperature exposures. While the mechanisms of freeze tolerance in intertidal species are poorly understood, many other freeze tolerant organisms use ice-binding proteins (IBPs) to modulate internal ice formation. IBP functions can include preventing ice formation, controlling ice crystal growth and encouraging ice formation. We hypothesized that ice-binding proteins exist in intertidal species and play a role in the variation in freeze tolerance seen both seasonally and between intertidal regions. We used bioinformatic methods to investigate whether IBPs are found in mussel genomes, resulting in putative IBPs being found in various mussel species as well as multiple other intertidal organisms. Putative sequences were then further investigated to determine if they evolved through refunctionalization, non-sense DNA, or lateral gene transfer. We then collected *M. trossulus* monthly from both the high and the low intertidal zone. Using ice shell purification, we then successfully isolated putative IBPs from *M. trossulus* and characterized their activity. This is the first description of IBPs in intertidal animals and adds to our knowledge of the evolution of IBPs.

BSP-10-3 Boyette, JL*; Bell, RC; Fujita, MK; Thomas, KN; Streicher, JW; Gower, DJ; Schott, RK; Berry College, Rome GA, California Academy of Sciences, San Fransisco, University of Texas, Arlington, Natural History Museum, London, National Museum of Natural History, Wahington, DC; *jack.boyette@vikings.berry.edu*

Evolution of non-visual opsin genes across life history transitions in frogs

Non-visual opsins are light-sensitive proteins expressed in the eyes, skin, and brain of many animals and are involved in various non-visual light detection functions, including circadian rhythm regulation, melatonin release, and pupillary responses. Previous research has primarily explored the function of non-visual opsins,

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with few studies investigating their molecular evolution. This project explored molecular evolution of non-visual opsin genes in frogs. From burrowing to aquatic and arboreal lifestyles, frogs inhabit a diverse array of light environments, which makes them a compelling system for studying the evolution of light detection mechanisms. Using whole eye transcriptomes from 84 frog species, and whole genome data from 16 species, we set out to 1) identify which non-visual opsin genes are expressed in the eyes of frogs; 2) compare selective pressure (dN/dS) among non-visual opsin genes; and 3) test for potential adaptive evolution by comparing selection between discrete ecological and life history classes (e.g. nocturnal vs. diurnal). We consistently recovered 12 non-visual opsin genes from frog eye transcriptomes, compared to 18 genes that we recovered genome-wide. Positive selection was detected in a subset of these genes. We also found variation in selective constraint between discrete ecological and life history classes, which may reflect functional adaptation in frog non-visual opsin genes. Although non-visual opsins remain poorly understood, these findings provide insight into their molecular evolution and potential function across frog diversity.

16-3 Boyle, WA*; Bodony, DJ; Shogren, EH; Nguyen, L; Day, EB; Kansas State University; *aboyle@ksu.edu*

More than meets the eye: high-speed video reveals aerobatic performance and the production of mechanical sounds in mating displays

Male manakins attract mates with diverse physical and acoustic displays. Understanding details of these displays has revealed novel mechanisms of sound production, the functional significance of other traits, and afforded insight into the process of sexual selection. However, some behaviors remain a mystery due to their high speeds including those of *Corapipo altera*. Most of this species' displays are performed at speeds resolvable by the human eye, occurring silently on or near an understory log. However, final, pre-copulatory elements involve an above-canopy flight followed by a high-speed dive and hop-about-face involving three distinct sounds ("flap-chee-wah") produced in unknown ways. We recorded 94 high-speed video clips capturing sub-canopy portions of this display, performed by nine males at four logs, and

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synchronized video with audio recordings. The flap occurs as the male emerges from a >35 m/s head-first dive by opening wings and rippling a gap through the primaries in a "Spock" move. The sound likely results from the unsteady aerodynamic force created by the sudden wing motion, a mechanism of sound production previously undocumented in Pipridae. Speed decreases to ~20 m/s via a "parachute," then the male swoops over the log, twisting, head-down, opening wings to bank and land backwards; the "chee" occurs during this twist. The final "wah" is vocal, occurring during the apex of an aerial cartwheel. Individuals were remarkably consistent in flight paths and landing locations when displaying alone, yet respond flexibly to female location. Individual differences hint at the ontogeny of performance and variation associated with female choice.

23-11 Boyle, M*; Schulz, A; Hu, D; Georgia Tech, School of Mechanical Engineering, Atlanta, GA, Georgia Tech, Schools of Mechanical Engineering and Biological Sciences, Atlanta, GA ; *mboyle@gatech.edu*

Elephant Trunks expand in volume when reaching for distant objects

Elephant trunks, mammalian tongues, and octopus arms are all examples of muscular hydrostats, structures composed mainly of muscles with no skeletal support. In 1985, biologist Bill Kier stated that since that muscles are mostly made of water, muscular hydrostats should be incompressible and satisfy volume conservation. In many organisms, this is the case: for example, an earthworm extends only by undergoing radial compression. In this experimental study, we high speed film an elephant reaching for distant objects. Using image analysis, we divide the trunk into four equal sections and find that all segments increase in length while maintaining girth, which is contrary to that suggested by conservation of volume. We discuss possible rationale for this phenomenon, from flow of blood into the trunk to expansion of nasal passages.

111-7 Braasch, I*; Spotted Gar Genome Consortium, ; Bowfin Genome Consortium, ; Michigan State University, Department of Integrative Biology, East Lansing, MI; *braasch@msu.edu*

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Odyssey of strange fish: Investigating 'ancient fish' genomes and development to illuminate vertebrate evolution

Ray-finned fishes - especially teleosts like zebrafish - are used to investigate the genomic basis of vertebrate development and evolution. However, teleosts are derived from a whole genome duplication (WGD) that had major impact on their genome and gene functions. Together with the two earlier vertebrate WGDs, this complicates macroevolutionary comparisons among vertebrates: WGDs led to lineage-specific genome reshuffling and gene losses, obscuring the distinction of orthologs vs. paralogs and hiding the origins of gene functions and developmental processes. We show that so-called 'ancient' holostean fishes (gars and bowfin), teleosts' sister lineage, have very informative genomes and body plans providing unique opportunities for comparative investigations. Holosteans serve both as 'unduplicated' outgroup to the 30,000 teleost species as well as an outgroup to lobe-finned vertebrates including 30,000 tetrapod species. Using examples from diverse developmental pathways and processes, we show that comparative genomic, developmental, transcriptomic, and epigenomic analyses with holosteans as "bridge species" are indispensable for connecting the often disparate sets of genes, gene regulatory elements, and morphologies among distant vertebrate lineages. The genome of our main holostean model species, the spotted gar (*Lepisosteus oculatus*), is representative of the bony vertebrate ancestor and retained numerous genes differentially lost in other lineages. The 'evolutionary inertia' of holosteans facilitates to find deep homology of regulatory elements across vertebrate lineages. Rearing gars in the laboratory, we developmentally test hypotheses about the evolutionary origins of vertebrate gene functions. Holosteans are thus integrative Evo-Devo models that illuminate vertebrate biology.

S5-12 Bradley, S*; Bailey, CDC; Bent, L; Howe, E; Vickaryous, MK; University of Guelph, ON, CAN, UofG, ON, CAN; *sbradl01@uoguelph.ca*

Nervous system compensation following tail loss and regeneration in the leopard gecko (Eublepharis macularius)

As for many lizards, leopard geckos (*Eublepharis macularius*) can voluntary self-amputate (autotomize) a portion of their tails in response to threatening stimuli. Tail loss results in a sudden

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reduction of body mass, changes in posture, and a shift of the center of mass. Over time a new tail is regenerated, but the position of the center of mass is never fully restored. As a result, lizards present a unique opportunity to investigate how the nervous system compensates when faced with mass-related perturbations. Here, we performed a spatiotemporal examination (before, during, and after tail regeneration) of cutaneous tactile sensitivity (mediated via the peripheral nervous system; PNS) and Purkinje cell neuromorphology (a key cell type of the central nervous system; CNS). We hypothesized that following tail loss and regeneration, the PNS and CNS would demonstrate evidence of somatosensory and neuromorphological changes to compensate for the alterations in mass. Using Semmes-Weinstein monofilaments, we identified regional differences in tactile sensitivity across the ventral surface of the original tail; the tail base is more sensitive than the tail tip. Within 30 days of tail loss, the tail is fully regenerated and tactile sensitivity restored. Using a modified Golgi-Cox staining method, we characterized and quantified the neuromorphology of Purkinje cells, the sole output cells of the cerebellum. We found there were localized changes to the dendritic arbor of Purkinje cells following tail regeneration. These data suggest that neuroplasticity may play a role in long-term compensation following tail regeneration. Together, these findings represent the first evidence of compensatory roles of both the PNS and CNS in a tail regenerating species.

80-8 Brainerd, EL*; Jimenez, YE; Weller, HI; Brown University; *ebrainerd@brown.edu*

Impact of whole-muscle shear and fascicle curvature on architectural gear ratio

Muscle fascicles in pennate muscles lie at an angle to the line of action of the muscle. When pennate muscles contract, the fascicles rotate as well as shorten, increasing the gear ratio of the whole muscle. Current pennate muscle models have added the effects of changes in muscle thickness (i.e. bulging) to the traditional planar models, demonstrating that muscle bulging can increase the architectural gear ratio (AGR) of pennate muscles as well as enable variable gearing under variable loading conditions. Most analytical models of muscle architecture assume that the fascicles start in a

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planar configuration and remain in that plane during muscle contraction, and they also assume straight, rather than curved, fascicles. Here, we introduce new models to demonstrate that these assumptions mask the impact of whole-muscle shearing and changes in fascicle curvature on AGR. These new analytical models lead to a generalized principle of dynamic architectural gearing in whole muscles: any deformation of a muscle that does not occur along the line of action, yet causes the muscle fascicles to lengthen along the line of action, will increase AGR. Conversely, any orthogonal deformation that causes the muscle fascicles to shorten along the line of action will decrease AGR. Whole muscle torsion can be added to the list of deformations that likely affect AGR, along with bulging, shear, and changes in fiber curvature, all of which can happen at the same time. To model real-world muscle contraction, this principle could be applied iteratively throughout the 3D volume of muscles with complex fascicle architectures to develop finite element models for AGR and variable gearing.

PREZ-1 Brainerd, EL; Brown University; *ebrainerd@brown.edu*
Welcome to the SICB Virtual Meeting!
The SICB President, Beth Brainerd, will introduce the SICB 2021 Virtual Annual Meeting and demonstrate some features of the online meeting platform. The meeting will begin with live symposia, plenary events and student prize presentations from January 3-7. Then it will continue for all of January and February with pre-recorded contributed papers and posters, live discussions for the contributed paper and poster sessions, social events, divisional business meetings, committee meetings, workshops and social events. All content will be recorded for viewing and text chat throughout all of January and February. President Brainerd will demonstrate the powerful features of the virtual platform for professional networking and catching up with friends and colleagues. This is still your familiar SICB meeting, just with more flexibility, more access to the scientific content and opportunities for broader participation from scientists and students everywhere.

BSP-7-5 Branam, E*; Wong, JY; Xu, K; Chan, BKK; Koehl, MAR; Chan, KYK; Swarthmore College, PA, Academia Sinica, Taipei, Taiwan,

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University of California, Berkeley, University of California, Berkeley; *ebranam1@swarthmore.edu*

Biomechanical role of dorsal thoracic spine in swimming of barnacle nauplii

Many marine invertebrates have complex life histories that begin with a planktonic larval stage. These larval invertebrates often possess protruding body extensions, but their function beyond predator deterrence is not well documented. For example, the planktonic nauplius larval form of Crustaceans have both spines and setae. Using the epibiotic pedunculate barnacle *Octolasmis spp.* as a model species, we investigated the hydrodynamic consequences of the dorsal thoracic spine on swimming nauplii. Video motion analysis was used to compare *Octolasmis spp.* naupliar swimming behaviors with their spines intact and with their spines removed. Our analysis showed that *Octolasmis spp.* without spines swam more slowly than those with spines. Larvae whose spines had been removed showed an alteration in limb beat pattern suggesting compensation for the loss of the spine. Nonetheless, nauplii without spines showed more backward motion during the recovery stroke and had jerkier trajectories than individuals with spines. The dorsal spine appears to affect feeding as well as locomotion. Preliminary particle image velocimetry of flow around dynamically-scaled physical models of nauplii of *Octolasmis spp.* with and without the dorsal thoracic spine indicated greater flux of prey-carrying water through the capture zone of the model with a spine. Thus, body extensions in planktonic larvae can affect key ecological functions such as locomotion and feeding.

BSP-9-4 Branch, HA*; Moxley, DR; Anstett, DN; Angert, AL; University of British Columbia; *haley.branch@biodiversity.ubc.ca*

Rapid evolution of leaf characteristics in response to drought stress in populations of scarlet monkeyflower (Mimulus cardinalis)

As global temperatures rise, extreme weather events are becoming more frequent. Between 2011-2016, the American west coast experienced a severe drought, creating a particular challenge for plants, especially those in riparian areas. This study seeks to understand how scarlet monkeyflower, *Mimulus cardinalis*, which occurs throughout Oregon and California, is adapted to diverse climates across their range, from historically wet environments in

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the north and drier in the south. This study examines how these populations responded to this severe perturbation and whether certain populations are better adapted to respond to future climatic change. We collected seeds of *M. cardinalis* from populations across the species' range prior to this drought and during the peak of the drought and used these seeds in a resurrection common garden experiment, where plants were exposed to either wet or dry treatments. By examining physiological and morphological characteristics of the leaves, we evaluate rapid evolutionary and plastic responses, as well as the evolution or loss of plasticity.

3-7 Brandley, NC*; Gilbert, FR; College of Wooster; *nbrandley@wooster.edu*

Does eye morphology predict predator avoidance behavior in the Carolina grasshopper (Dissosteira carolina)?

Sensory organs are notoriously expensive to develop and maintain, and therefore face strong selective pressures to maximize detection of relevant information. As such, researchers often believe that an organism's sensory systems should match their behavioral needs. However, the behavioral responses are often left untested, and sensory specializations may not act uniformly across all behavioral tasks. For example, Carolina grasshoppers (*Dissosteira carolina*) have unusual eyes that are both 1) sexually dimorphic (females have larger eyes with finer visual acuity) and 2) specialized for vision in the vertical axis. However, it is unknown whether either of these visual characteristics predict their behavior in response to approaching predators. Here, we present Carolina grasshoppers (n=67) with a series of computer-generated stimuli designed to exploit these visual differences while simultaneously recording their response via the EthoVision XT tracking system. Our results will elucidate whether particular characteristics of Carolina grasshopper's eyes are matched to their predator avoidance behavior.

5-5 Brandt, EE*; Duke, S; Wang, L; Mhatre, N; University of Western Ontario; *ebrandt3@uwo.ca*

Baffling behavior: why don't more crickets use acoustic tools?

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Why is tool use rare among insects? For example, a few species of tree crickets build acoustic baffles that nearly double their calling efficiency. Such baffle use could benefit many of the > 900 known cricket species, yet, no other crickets make baffles. It has been hypothesized that tool-use in insects is rare because tool-use is stereotyped and derived from similar pre-existing behaviors, and appropriate behaviors are rarely available. An alternative explanation is that tool-use lacks sufficient utility to drive its evolution in the first place. Here, to quantify the utility of acoustic tools, we investigated the sound production efficiency of cricket wings across the phylogeny. First, we measured wing sizes, shapes, and calling frequencies for species across the gryllid phylogeny. Next, we used finite element analysis to model the sound field emanating from cricket wings and song frequencies lying within the natural range. By mapping data from real crickets onto our predicted landscape of efficiency, we determined the theoretical highest maximum efficiency achievable at a given frequency, Finally, since the environment also dramatically affects how a call is propagated, we created a second set of models which incorporated acoustic transmission losses in different habitats and modeled sound propagation with different sender and receiver positions. Using these models, we could predict and quantify the probable utility of acoustic tool use among crickets, providing insight into the drivers behind the rarity of acoustic tools in crickets.

107-5 Breit, AM*; Levesque, DL; University of Maine; *ana.breit@maine.edu*

Not all endotherms are homeotherms: the importance of high-quality, accurate thermoregulatory datasets

All mammals are endothermic and capable of maintaining stable body temperatures. However, because of the high energetic cost of defending high body temperatures, many mammals vary their body temperature in response to changes in ambient temperature to save energy. The breadth and limits of the thermoneutral zone, the range of environmental temperatures where minimal energy is required to thermoregulate, vary among species. Early studies of the thermoneutral zone focused predominantly on species found in the northern hemisphere and relatively few physiological studies have

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been conducted in the tropics, leading to biased generalizations of thermoregulation. Contrary to holarctic species, tropical mammals evolved within a narrow range of temperatures, potentially leading to alternative thermoregulatory phenotypes. By fluctuating body temperature with changing ambient temperatures, species can save energy in response to changing weather conditions. We hypothesize that by increasing their flexibility of body temperature regulation, tropical species can effectively expand their thermoneutral zone, resulting in greater thermolability and thus a greater range of inhabitable temperatures. To test this and other hypotheses on the evolution of mammalian thermoregulation, we are assembling a high-quality database containing thermoregulatory data from hundreds of mammals, which can be used to test predictions of different species' reactions to climate change. The dataset contains species' body temperature in relation to the upper and lower limits of the thermoneutral zone and metabolic rates at those limits. Our dataset quantifying the upper and lower limits to the thermoneutral zone in species across latitudes allows us to better understand the evolution of mammalian thermoregulation.

88-10 Breitenbach, AT*; Paitz, RT; Bowden, RM; Illinois State University; *atbreit@ilstu.edu*

Do thermal fluctuations affect gene expression differently than constant conditions?

The complexity of environmental factors is often greatly simplified in ecological studies, which may result in outcomes that do not accurately reflect biological responses under natural circumstances. For example, in many turtle species with temperature-dependent sex determination (TSD), cooler incubation temperatures induce the expression of genes necessary for testis development (i.e. *Dmrt1*), while warmer temperatures induce the expression of genes necessary for ovary development (i.e. *Cyp19A1*). However, these patterns were characterized using constant temperatures, which do not accurately reflect the thermal fluctuations experienced during natural incubation conditions. We hypothesized that the timing of upregulation for genes involved in sexual differentiation differs between constant and fluctuating temperatures. We predicted that fluctuating incubation conditions would delay the induction of sexual differentiation because embryos

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receive thermal cues for both sexes. To investigate this, we exposed red-eared slider (*Trachemys scripta*) embryos to two conditions that produce all male hatchlings (26 ° C and 26 ± 3 ° C) and two that produce all female hatchlings (31 ° C and 31 ± 3 ° C). Gonads were sampled during multiple points across the middle third of development, when sex is sensitive to temperature effects, and the expression of *Dmrt1* and *Cyp19A1* was quantified. From these data, we will be able to determine how the expression of gonad-specific genes varies between constant and fluctuating temperatures. Designing experiments with high ecological relevancy will prove critical in understanding how biological systems operate outside the laboratory.

S3-2 Brennan, PLR*; Sterett, M; DiBuono, M; Klo, K; Marsden, R; Schleinig, P; Tanner , L; Purdy, S; Mount Holyoke College; *pbrennan@mtholyoke.edu*

When the uterus is a vagina: Intra-horn insemination in the alpaca and consequences to genital morphology coevolution and 3-D shape

Alpacas are among the few mammalian species where insemination is reportedly transcervical. Transcervical insemination is expected to be be rare in mammals, because the penis can be a vehicle for disease transmission, and female upper reproductive tract immunity is typically downregulated for pregnancy to succeed. However, evidence for transcervical insemination in alpacas was only circumstantial. Here we performed mating experiments with females that were going to be culled at a meat farm, and determined that the penis tip of the male enters not only the cervix, but travels the entire length of the reproductive tract all the way to the end of the uterine horns. We further studied the 3-D morphology of male and female genitalia and report oddities of their morphology that may be associated with this unusual insemination mode. The cranial vagina varies between bulbous and straight, while the caudal vagina is typically narrower. The cervix consists of a series of 2-3 spirals, and it is in an open state most of the time. The uterus and uterine horns have a complex shape with multiple constrictions. The male alpaca has a cartilaginous penis tip and a keratinized nail that may help to push against these constrictions, resulting in extensive damage to the female tract. In effect, the entire female reproductive tract of the female is behaving like a vagina,

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and its modifications likely extend beyond the morphology, into immune adaptations to manage uterine wounding, and potential pathogen exposure.

4-8 Bressman, NR*; Morrison, CH; Ashley-Ross, MA; Chapman University, Orange, CA; Wake Forest University, Winston-Salem, NC, Wake Forest University, Winston-Salem, NC; *noahbressman@gmail.com*
Reffling: a novel locomotor behavior used by Neotropical armored catfishes (Loricariide) in terrestrial environments
Armored catfishes (Loricariidae) are known to exhibit terrestrial behaviors, but these have been poorly described. The goals of this study are to describe (1) the terrestrial locomotion of 4 loricariid species (3 *Pterigoplichthys*, 1 *Hypostomus*), (2) how their armored morphology may affect terrestrial locomotion, and (3) how behavior, performance, and kinematics relate to species and endurance. The terrestrial locomotion of the 4 species was recorded using high-speed cameras. Videos were digitized in MATLAB and ImageJ to compare performance and kinematics between species and subsequent locomotor sequences. Morphology was described using &microCT scans and dissections. Loricariids use a novel, highly asymmetric form of axial-appendage-based terrestrial locomotion involving their mouth, paired fins, posterior axial body, and tail. As this behavior is so unlike any other described locomotor behavior, we have created a new word to describe it: reffling. These species have numerous unique morphological traits that may greatly reduce body and fin flexibility. Because loricariids are so inflexible, they may be constrained into reffling as their only means of terrestrial locomotion, but their stiffness may improve force transmission, allowing them to be among the fastest fishes on land. Overall, all 4 species had very similar terrestrial kinematics and performance. Their performance generally declined over time, but different species had different endurance levels. Because many loricariid species are invasive throughout the world, it is important to consider their capacity to disperse into new bodies of water overland in management plans and risk assessments.

BSP-5-4 Brianik, CJ*; Geraci-Yee, S; Collier, J; Allam, B; Stony brook university; *christopher.brianik@stonybrook.edu*

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Completing the life cycle of QPX: evidence of zoospores and description of a new replication pathway

Quahog parasite unknown (QPX) is an opportunistic thraustochytrid parasite of the hard clam, *Mercenaria mercenaria*, that has been attributed to millions of dollars in losses due to numerous mass mortality events. Despite QPX being recognized for over 50 years and maintained in culture for over 20 years, the complete life cycle of this parasite has remained elusive precluding thorough understanding of its biology. In particular, presence or absence of a zoospore stage (motile dispersal stage) similar to that of other thraustochytrids remained unclear. By modulating culture conditions, QPX zoospores have been successfully and reliably produced from lines maintained in culture for extended periods, as well as newly isolated lines. In addition to the confirmation of zoospores, new stages in QPX replication were also observed with a possible life cycle proposed. The factors that primarily influence zoosporulation in QPX include the removal of mucus from cultured cells, culture age, and temperature. Preliminary infection trials using bath exposure demonstrated no direct infectivity of zoospores, implying that additional stressors are required to produce infections, however, this requires further testing. These findings provide valuable information on the basic biology of the parasite, enabling a better understanding of mechanisms controlling QPX dynamics in the environment and in clams.

71-6 Bribiesca-Contreras, F*; Daley, MA; Badri-Spröwitz, A; Max Planck Institute for Intelligent Systems, University of California, Irvine; *bribiesca@is.mpg.de*

Effects of tendon-network mechanisms on avian terrestrial locomotion

Bipedalism has evolved independently in archosaurs and primates, represented today in birds and humans. Birds show exceptional terrestrial locomotor agility and great variety of lifestyles. Yet, the basic arrangement of their hindlimb skeleton and patterns of walking, running, and even hopping, are highly conserved across species. Musculoskeletal morphology of the pelvis and hindlimb have been investigated in a variety of birds, spanning from small crouched (e.g. passerines) to large upright-leg stance (e.g. ratites) species. Birds can generate high muscle power necessary

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for propulsion through a multi-jointed system of interconnected multi-articulated muscles, functionally connecting the proximal and distal leg. This tendon-network configuration supports energy transfer between the joints for self-stabilisation of striding gaits and self-organisation of the system dynamics, which allows for correction of angular motions with no explicit feedback control. In this work, we will investigate the effect of multi-articular muscles in avian terrestrial locomotion. This will be done in a comparative framework between birds with crouched and upright-limb posture to identify mechanisms of body weight support and control of distal leg mechanics used during gait. 3D time-lapse imaging will be used to investigate joints 3D position in a series of postures representing different stages of the gait cycle. In addition, the full ranges of flexion and extension angles of multi-articular muscles will be quantitatively assessed via tendon travel method.

72-5 Brocklehurst, RJ*; Fahn-Lai, P; Regnault, S; Pierce, SE; Harvard University, Cambridge, MA, USA, University of Surrey, Guildford, UK; *rbrocklehurst@fas.harvard.edu*

Stepping up: Musculoskeletal modelling of sprawling and erect forelimbs

Extant mammals are ecologically diverse, having evolved a remarkable array of locomotor ecologies. Evolution of the therian-type forelimb was a key innovation, and musculoskeletal reorganization of the forelimb in therians is also associated with the acquisition of upright posture. Despite a rich fossil record, disagreement persists over when major functional changes in forelimb use and posture occurred during the evolution of mammals, exacerbated by lack of data from extant analogues. To investigate the functional impacts of forelimb reorganization in therians, we created digital musculoskeletal models of three extant taxa which span the sprawling-erect transition; *Salvator merianae*, a sprawling reptile; *Tachyglossus aculeatus* a sprawling monotreme mammal; and *Didelphis virginiana*, an upright therian mammal. From the musculoskeletal models we estimated and compared osteological range of motion (ROM) as well as muscle moment arms (MMA) at the shoulder joint. Based on published *in vivo* data, we predicted that ROM and MMA would be highest for forelimb long-axis rotation in sprawling

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taxa, and for flexion in upright taxa. The upright *Didelphis* did have the highest MMA for forelimb flexion, but our other predictions regarding long-axis rotation were not met; the sprawling taxa, *Tachyglossus* and *Salvator*, were better characterized by greater abduction MMA and high abduction-adduction ROM. Our data reveal a complex overall pattern, with each taxon showing a unique combination of biomechanical traits. We suggest that the sprawling-erect transition in the mammalian lineage was likely not straightforward, and there is important biomechanical variation within each of these broad locomotor categories.

96-10 Brokaw, AF*; Page, RA; Smotherman, M; Texas A&M University, College Station, TX, Smithsonian Tropical Research Institution, Gamboa, Panama; *afbrokaw@tamu.edu*

Finding fruit: Olfactory search strategies in a neotropical bat

Animals rely on chemical signals to detect, identify, discriminate, and find the resources critical for their survival and fitness, including food, shelter, and mates. Detecting and following chemical cues is challenging, and animals that search using smell display a diversity of morphological, physiological and behavioral adaptations. A decrease in speed and an increase in sampling rates are commonly used behavioral strategies when odor tracking in a turbulent olfactory environment. As flying, echolocating mammals, bats face constraints related both to change in speed and sampling (sniffing), yet odors cues are thought to be important for fruit and nectar feeding bat. Using a behavioral assay combined with three-dimensional tracking software, we quantified the olfactory search behaviors in flying Jamaican fruit-eating bats (*Artibeus jamaicensis*). Wild individuals were trained to seek out an odor reward (banana) or odor only (banana extract) from among five potential options in a flight cage. Bats were highly successful at choosing the scented platform for both banana and odor only treatments. However, bats rarely investigated the correct platform first, and instead investigated an average of three out of the five platforms before making a choice. During these investigation flights, bats did not significantly reduce their speed, but did get very close to the odor. Together, this suggests that rather than using odor plume information for locating odor source, bats use a serial sampling strategy to locate, discriminate and then choose an

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odor source. Understanding the role of olfactory cues in foraging decisions and search behaviors of bats may have important implications for understanding how bats use the landscape, and how habitat loss may influence search behaviors.

99-8 Brunner, LR*; Hurley, LM; Indiana University; *laribrun@iu.edu*
The effects of unfamiliar male odor during squeak playback on male mouse vocalizations
During courtship interactions, house mouse vocal behavior is highly context-dependent. Ultrasonic vocalizations (USVs) are prosocial signals used by male house mice during courtship. Males modulate their USV production in response to external factors, including signals from conspecifics. Female house mice often produce negatively valenced broadband vocalizations (BBVs), or squeaks, when rejecting the advances of a male during courtship. In response to female BBVs, male mice decrease their USV production. Using a paradigm that allows us to observe male behavior and vocalizations during a courtship interaction with limited contact between the male and female, we measured the response of dominant and subordinate males to situations with varying conspecific odor cues. We employed a 15-minute playback consisting of 5 minutes of silence, followed by 5 minutes of exemplar BBV playback, and finally another 5 minutes of silence to see how USV production changes in response to playback of BBVs. Both dominant and subordinate males experienced this playback in two different conditions: the female control (F) condition in which odor cues (in the form of soiled bedding) from a female mouse were present, and the female plus male (FM) condition in which odor cues from a female and from unfamiliar male mice were present. We hypothesized that dominants would decrease their USV output less than subordinates in the FM condition due to dominants expending more energy in response to a potential social competition threat. All males except one, regardless of their social hierarchical status, decreased their total USV production during the interaction in which unfamiliar male odor was present. This indicates that unfamiliar male scent during perception of courtship rejection signals decreases male mouse vocal output, and this effect is independent of hierarchical status.

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S11-5 Bryce, CM; University of California, Santa Cruz; *cbryce@ucsc.edu*

Dogs as pets and pests: Global patterns of dog activity and health

Dogs (*Canis familiaris*) were the first domesticated species and, at an estimated population of 1 billion individuals, are globally ubiquitous today. Describing the tremendous morphometric diversity and evolutionary origins of dogs is a scientific endeavor that predates Darwin, yet our interdisciplinary understanding of the species is just beginning. Here, I present global trends in dog activity and health. While the human-dog relationship has for millennia been close, it is also complicated. As pets, companion dogs are often treated as family and constitute the largest sector of the ever-growing $300 billion USD global pet care industry. As pests, feral dogs are an emerging threat to native species via both predation and non-consumptive effects (e.g. chasing, harassment, competition for resources). Furthermore, I briefly discuss mounting evidence of dogs as not only infectious disease reservoirs but also as bridges for the transmission of pathogens between wild animals and humans in zoonotic spillover events. Dog mobility across the urban-wildland interface is an important driver for this and other adverse effects of canines on wildlife populations and is an active topic of disease ecologists and conservation biologists. Other canine scientists, including veterinary clinicians and physiologists, study more mechanistic aspects of dog mobility: the kinetics, kinematics, mechanics, and energetics of dog locomotion. I outline the prevalent methodological approaches and breed-specific findings within dog activity and health research, then conclude by recognizing promising technologies that are bridging disciplinary gaps in canine science.

88-1 Bryla, A*; Zagkle, E; Sadowska, ET; Cichon, M; Bauchinger, U; Jagiellonian University, Krakow, Poland, Jagiellonian University, Krakow, Poland; Nencki Institute of Experimental Biology, Warsaw, Poland ; *amadeusz.bryla@doctoral.uj.edu.pl*

Body temperature as indicator and driver for costs associated with avian humoral immune response

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From an eco-immunological perspective, the resistance to a pathogen is a costly trait for an organism, but efforts to qualify and quantify these costs are ambiguous. The humoral immune response is relatively slow and complex so that the quantification of its energy cost through a single time-point metabolic measurement is questionable. Here, we compared immune challenged and control zebra finches (*Taeniopygia guttata*) and estimated costs of the mounted humoral immune response through a combination of three different measurements, core body temperature, energy metabolism at rest, and markers for oxidative stress in the plasma. Body temperature was recorded continuously through implanted data loggers, whereas we measured resting metabolic rate and oxidative status only on day 7 post-challenge, at the expected peak of antibody production. The immune challenged birds revealed higher oxidative damage, a result that was not driven by the energy metabolism immediately measured before the blood sampling. Core body temperature, however, was higher during the first three nights in the challenged birds versus controls suggesting a higher metabolism during the initial phase of the immune response and was neither different after this, nor during the daytime throughout the experiment. The continuous measurement of body temperature provides indirect evidence for elevated energy metabolism associated with an immune response only in the very first days. In addition, elevated oxidative stress represents another cost associated with the immune response that is presumably driven by the energetic costs of this response.

53-6 Brzęk, P*; Roussel, D; Konarzewski, M; University of Białystok, Poland, University of Lyon, France; *brzek@uwb.edu.pl*
Divergent selection for basal metabolic rate in laboratory mice affected organ size rather than mitochondrial activity
Intra-specific variation in basal metabolic rate (BMR) has profound evolutionary, ecological, and biomedical consequences. However, functional mechanisms responsible for this variation are still not fully understood. Theoretically, variation in BMR can reflect differences in either the mass of internal organs, and/or in the rate of organ mass-specific metabolic processes. Here, we compared parameters quantifying mitochondrial metabolic activity in two lines of laboratory mice, divergently selected for either high (H-BMR) or low (L-BMR) level of BMR. H-BMR mice had larger liver and

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kidneys, i.e. organs that are important predictors of BMR. On the other hand, our preliminary data offer little evidence that selection affected intrinsic properties of mitochondria like mitochondrial activity and efficiency, or activity of mitochondrial enzymes like citrate synthase and cytochrome c oxidase. We conclude that variation in BMR observed between both selected lines reflects mainly changes in organ size rather than in mitochondrial-specific metabolic rate. These results, together with earlier analyses of cell membrane composition, suggest that divergent selection for BMR either did not affect metabolic parameters at molecular level or modified them in counter-intuitive direction. We discuss other potential mechanisms of difference in BMR between these lines.

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92-12 Buchinger, TJ*; Fissette, SD; Bussy , U; Li, K; Huerta, B; Buchinger, EG; Brant, CO; Johnson, NS; Li, W; Michigan State University , US Geological Survey Hammond Bay Biological Station; *tjbuchinger@gmail.com*

A pheromone antagonist deters female sea lamprey from more senescent mates

Male sea lamprey (*Petromyzon marinus*) release a multi-component sex pheromone that attracts females and elicits courtship behaviors. Previous research indicates the male pheromone mimics a nonsexual larval cue, but that females discriminate between the larval cue and male pheromone – which each consist, in part, of the attractant 3kPZS – using the larval compound PZS as a behavioral antagonist of 3kPZS. Although PZS is the more abundant component in the larval cue and 3kPZS the more abundant component in the male pheromone, males produce high physiological concentrations of PZS as a precursor to 3kPZS and release small quantities of PZS into the water. To test the hypothesis that male variation in PZS release guides female mate choice, we 1) characterized male variation in release of 3kPZS and PZS and 2) determined whether females can discriminate among males' pheromone signals using variation in PZS release. Wild males sampled off spawning nests released 3kPZS and PZS at ratios ranging from 1.5:1 to 263:1 (3kPZS: PZS; n = 77). Repeated sampling from the onset of sexual maturation until death, which occurs naturally at the end of lamprey's single spawning season, revealed that males gradually released more PZS. In an in-stream behavioral assay, females preferred mixtures of 3kPZS and

PZS at ratios typical of recently matured males (90:1) over males nearer to death (30:1). Sperm analyses indicated that males with the most preferred 3kPZS: PZS ratio had lower quality sperm than less preferred males. We postulate that avoidance of PZS arose as a mechanism to prevent orientation towards larvae, but incidentally biases female choice away from males closer to senescence.

61-3 Buckley, LB; University of Washington; *lbuckley@uw.edu*
TrEnCh: Tools for translating environmental change into organismal responses
Many efforts to forecast ecological responses to climate change are based on air temperatures at coarse spatial (degrees) and temporal (months) resolutions, but animals respond to multiple aspects of the environment at scales of minutes and meters. We aim to improve ecological and evolutionary forecasts by providing computational and visualization tools to address these discrepancies. The TrenchR R package facilitates microclimate modelling to translate weather station data into the environmental conditions experienced by organisms and biophysical modelling to predict organismal body temperatures given the environmental conditions. Interactive visualizations explore organismal responses to environmental conditions. Several use biophysical modelling to explore body temperatures and regions of thermal stress for a variety of taxa. Another leverages a database of insect development traits to predict phenology. TrEnCh-ed includes interactive R Shiny applications and associated tutorials to allow students and others interested to explore the ecological and evolutionary impacts of climate change through interacting with data. A series of tutorials introduces graduate students and other researchers to biophysical ecology. We aim to improve ecological and evolutionary forecasting tools for education, policy, and research and welcome your ideas and input.

6-4 Buendia Castillo, D*; Stanley, C; Naidugari, J; McCubbin, S; Nethery, B; Dupont-Versteegden, E; Cooper, R L; University of Kentucky ; *buendiad@uky.edu*
Conducting authentic curriculum undergraduate research experiences (ACUREs) in teaching laboratories

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Modifying typical physiological laboratory protocols to not only teach, but also conduct authentic research aimed for scientific publications, is very engaging for students. However, there are caveats in conducting experiments in a reproducible manner within a teaching lab with multiple student-driven stations. One approach that appears to offer an authentic research experience while still providing reliable results is to conduct a series of experiments prior to the course to be taught, and have students in the course run the same experiments to compare the novel findings. To reduce biases in analysis, the students are blind to the treatments and can analyze the novel data collected before the teaching lab, as well as their own data collected in class. Knowledge that their data will be peer-reviewed has resulted in students' heightened attention to detail in conducting the experiments and analyses. When presenting the results for publication, the data collected prior to the class is used, as it is tightly controlled to reduce experimental and analysis variability. The classroom results are presented separately with explanations for variation in the experimentation and analysis. We have conducted this approach for six different ACUREs. Student and teaching assistant evaluations of this approach are provided. This approach is also useful for repository data sets provided in scientific publications.

44-8 Bukovich, IMG*; Friesen, CR; Parker, MR; James Madison University, Harrisonburg, VA, University of Wollongong, NSW, Australia; *bukoviim@dukes.jmu.edu*

Influence of testosterone on pre- and post-copulatory dimensions of male-male competition in the red-sided garter snake, Thamnophis sirtalis parietalis

Intense competition drives male vertebrates to adopt alternative reproductive strategies to outcompete other males. Thousands of male red-sided garter snakes (*Thamnophis sirtalis parietalis*) emerge every spring in Manitoba, Canada, and engage in robust competition to mate with females. Sexual selection has facilitated the evolution of post-copulatory mechanisms in male garter snakes (e.g., sperm competition) as well as alternative reproductive strategies (e.g., female pheromone production, other forms of female mimicry). Female mimics in this species benefit from known thermoregulatory advantages; however, unidentified evolutionary

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advantages may result from the three-fold higher circulating androgens found in female mimics versus normal males. To test this, male garter snakes were implanted in July 2019 with either a SHAM or testosterone-containing silastic implant (n=15 per group). Snakes were bled monthly for implant validation then artificially hibernated in December. In May 2020, snakes were tested in the laboratory for courtship intensity using established scoring metrics in simulated mating aggregations. Sperm analyses were then conducted to investigate potential differences in sperm count and morphology between the treatments. Testosterone treatment is predicted to invigorate courtship behavior by its known actions in sexually dimorphic regions of the male vertebrate brain. Previous experiments on testosterone effects on testis function in reptiles vary, so our study will clarify whether testosterone enhances sperm characteristics. Our results may reveal previously unknown advantages in female mimics activated by higher concentrations of circulating androgens.

11-7 Bukovich, IMG*; Richard, SA; Tillman, EA; Jayamohan, S; Humphrey, JS; Carrington, PE; Bruce, WE; Kluever, BM; Avery, ML; Parker, MR; James Madison University, Harrisonburg, VA, USDA APHIS NWRC, Gainesville, FL, USDA APHIS NWRC, Gainesville, FL; *bukoviim@dukes.jmu.edu*

Conspecific chemical cues facilitate mate trailing by invasive Argentine black and white tegus

Squamate reptiles (snakes and lizards) rely on chemical cues from conspecifics to search the environment for potential mates. How such cues are used by invasive species in reproduction is a key question in multiple, independent invasions throughout the Southeastern U.S. The Argentine black and white tegu lizard (*Salvator merianae*) is an invasive reptile species in south Florida threatening native fauna in biodiverse regions such as Everglades National Park. By testing both male (n = 7) and female (n = 7) tegus in a Y-maze apparatus, we assessed if either sex follows chemical trails left by conspecifics and if behaviors were sex- or season-specific. We conducted three types of trials where conspecifics created odor trails: Male-only (male scent only in base and one arm of Y), Female-only, and Male vs. female. Males did not preferentially follow scent trails from either sex, but they

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did differentially investigate conspecific scent from both sexes. Males also had reduced turning and pausing behavior while trailing in the spring and showed seasonal upregulation of chemosensory sampling in spring. Female tegus exhibited stronger conspecific trailing abilities than males, following both male and female scent trails, and they explored the maze less before making an arm choice. Females also investigated the scent trails intensely compared to males (more passes in scented arms, more time with scent trails). Our results demonstrate for the first time than females of an invasive reptile species can follow conspecific scent trails and provide potential avenues for development of control tools.

BSP-1-6 Burford, BP*; Robison, BH; Stanford University, Monterey Bay Aquarium Research Institute; *bburford@stanford.edu*

Bioluminescent backlighting illuminates the visual signals of a social squid in the deep sea

Visual signals rapidly relay information, facilitating behaviors and ecological interactions that shape ecosystems. However, most known signaling systems can be restricted by low light levels—a pervasive condition in the deep ocean, the largest inhabitable space on the planet. Resident, visually-cued animals have therefore been hypothesized to have simple signals with limited information-carrying capacity. We used cameras mounted on remotely operated vehicles to study the behavior of the Humboldt squid, *Dosidicus gigas* in its natural deep-sea habitat. We show that specific pigmentation patterns from its diverse repertoire are selectively displayed during foraging and in social scenarios, and we investigate how these behaviors may be used syntactically for communication. We additionally identify the probable mechanism by which *D. gigas*, and related squids, illuminate these patterns to create visual signals that can be readily perceived in the deep, dark ocean. Numerous small subcutaneous photophores (bioluminescent organs) embedded throughout the muscle tissue make the entire body glow, thereby backlighting the pigmentation patterns. Equipped with a mechanism by which complex information can be rapidly relayed through a visual pathway under low light conditions, our data suggest that the visual signals displayed by *D. gigas* could share design features with advanced forms of animal communication. Visual

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signaling by deep-living cephalopods will likely be critical in understanding how, and how much, information can be shared in one of the planet's most challenging environments for visual communication.

66-1 Burnett, NP*; Badger, MA; Combes, M; University of California, Davis; *burnettnp@gmail.com*

Shooting the gap: how bees protect their wings in windy, dynamic obstacle courses

Bees frequently forage in habitats with cluttered, wind-blown vegetation. Collisions with clutter and other obstacles can cause irreversible wing damage that impairs future flight performance and leads to mortality. We know little about the strategies that bees use to protect their wings when transiting narrow gaps between obstacles, like those in cluttered vegetation. We tested how the Valley Carpenter Bee *Xylocopa varipuncta* protects its wings while transiting a dynamic obstacle course that mimicked wind-blown vegetation, using a factorial design that varied obstacle motion (stationary or moving) and wind (still air, head- or tailwinds). We filmed bees flying through obstacle fields with gaps that were approximately equal to their wingspan, and quantified flight speed, yaw angle (relative to flight tunnel axis), and number of wing collisions with obstacles. Bees often increased their body yaw (i.e. turned sideways) during transits, and larger yaw angles were associated with fewer wing collisions. Bees reached higher maximum yaw angles when transiting stationary obstacles or when flying in still air, and as a result, they experienced fewer wing collisions in these conditions. On average, bees maintained similar ground speeds across all wind and obstacle conditions, but trials with faster ground speeds were associated with more wing collisions, possibly because bees had less time to turn their bodies before transiting the obstacles. When controlling for variation in body yaw and ground speed, there were similar numbers of wing collisions across all obstacle and wind conditions. This suggests that the high rate of wing collisions associated with wind and obstacle motion is driven mostly by the extent to which these conditions prevent bees from enacting their strategy of yawing to avoid wing damage.

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S8-1 Burns, M*; Stellwagen, SD; University of Maryland, Baltimore County, University of North Carolina, Charlotte; *burnsm@umbc.edu*

The ties that stick: an introduction to sticky biomaterials

Adhesion is a chemical or mechanical effect of substances used by organisms to construct domiciles, capture prey, secure offspring, and navigate complex environments. This symposium has been curated to showcase creative research on sticky biomaterial properties, production, and applications by incorporating speakers with diverse study systems, including plants, mollusks, arthropods, and vertebrates. With new progress in sequencing technologies, increasing knowledge of the natural history of organisms that produce adhesive materials, and the development of flexible methods and instrumentation for measuring fine forces, we hope that this symposium will encourage progress on biomimetics and appreciation for the biochemical array of adhesives found in nature.

67-5 Busby, MK*; Davidowitz, G; Bronstein, JL; The University of Arizona, Tucson, AZ; *mkbusby@email.arizona.edu*

Will carpenter bee (Xylocopa californica) nest temperatures exceed larval CTmax?

As climate warms, temperatures are more likely to exceed organisms' upper thermal limits, especially in already hot and arid regions. Species whose life histories expose them to temperature extremes will experience the hottest temperatures, and unlike broader-scale climate patterns, microclimate changes are harder to predict. But microclimates are often the proper scale for considering temperatures of insect habitats. Despite the importance of this fact in predicting whether insects will survive extremes, in-nest temperatures experienced by developing bees are largely unknown. The desert carpenter bee (*Xylocopa californica*) is an aboveground-nesting bee and a common pollinator in desert ecosystems. We asked what temperatures carpenter bees experience inside their nests, and whether the nest substrate insulates against temperature extremes. To test this, we installed 8 paired thermocouple probes inside and outside 60 active carpenter bee nests in southern Arizona and compared internal and external temperatures. We also compared temperatures within nest substrates to air temperatures from a

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nearby weather station. Larval CT_{max} was determined using flow-through respirometry. Nest temperatures were measured during 2020, the hottest summer on record in southern Arizona, and are presented in the context of larval thermal tolerance.

19-5 Bush, JM*; Ellison, M; Simberloff, D; University of Tennessee Knoxville, Oklahoma State University; *jbush15@vols.utk.edu*
Territory owners, floaters, and sneaker males use different behavioral strategies in green anole lizards (Anolis carolinensis)
Many studies have explored the mechanisms behind territory establishment and dominant-submissive dynamics in *Anolis* lizards. Much of this work has focused on the behaviors of large territorial males, with little attention paid to non-territorial floaters and small "sneaker" males. In this study, we explored behavioral differences between males exhibiting different territorial behaviors, particularly focusing on their interactions with each other and with females. We recorded the behaviors of 12 captive populations of green anole lizards (*Anolis carolinensis*) with 12 individuals each (6 males, 6 females) housed in semi-natural enclosures. We categorized males as territory owners, floaters, or sneakers using criteria of site fidelity and defensive behaviors and compared interactions within and between each category using linear mixed effects models. Half of the males in our populations displayed non-territorial phenotypes, demonstrating that these males likely make up an important component of anoles' social landscape in the wild. Furthermore, each category was characterized by different behaviors, with territory owners engaging in the most behavioral interactions and sneakers behaving more similarly to females than to other males across all variables measured. Females also differentiated between territorial and non-territorial males, directing more displays at territory owners despite high home range overlap with floaters and sneakers. This study supports the female mimicry hypothesis for sneaker males in anoles and indicates the importance of considering the diversity of territorial strategies employed by green anole lizards in studies of their spatial and social behaviors.

90-5 Buss, N*; Nelson, KN; Hua, J; Relyea, RA; Binghamton

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University, Biological Sciences Department, Binghamton, NY , Rensselaer Polytechnic Institute, Department of Biological Sciences, Troy, NY ; *nickrbuss@gmail.com*

Effects of different roadway deicing salts on host-parasite interactions: the importance of salt type

The application of roadway deicing salts is increasing the salinity of freshwater systems around the world. Increased salinization from deicing salts such as NaCl, $CaCl_2$ and $MgCl_2$ can have direct, negative impacts on freshwater organisms at concentrations found in nature. Yet, our understanding of how these salts can indirectly impact freshwater organisms by altering important ecological interactions, such as those between host and parasite, are less understood. Using an amphibian (*Rana sylvatica*) -trematode (*Echinostoma spp.*) model, we examined whether exposure to NaCl, $CaCl_2$ or $MgCl_2$ 1) influences trematode mortality; 2) alters amphibian-trematode interactions; and 3) alters larval amphibian activity (behavior associated with parasite avoidance). We found that exposure to $CaCl_2$ greatly reduced trematode survival across all Cl^- concentrations (230, 500, 860 and 1000 mg Cl^- L^{-1}) while NaCl and $MgCl_2$ had no effect. Conversely, when both host and parasites were exposed to salts, NaCl, but not $CaCl_2$ or $MgCl_2$, increased infection. The lack of effect of $CaCl_2$ on infection was likely driven by $CaCl_2$ reducing trematode survival. Exposure to NaCl increased infection at 500 mg Cl^- L^{-1}, but not 230 or 860 mg Cl^- L^{-1}. However, unlike previous studies, this increase of infection was not due to salt exposure altering tadpole behavior. Overall, our results suggest that NaCl at environmentally relevant concentrations can negatively impact amphibian populations indirectly by increasing their susceptibility to parasites.

S9-6 Butler, JM*; Maruska, KP; Louisiana State University and Stanford University, Louisiana State University; *jmbutler@stanford.edu*

Reproductive state-dependent visual plasticity in a cichlid fish

Animals use visual communication to convey crucial information about their identity, reproductive status, and sex. Plasticity in the auditory and olfactory systems has been well-documented, however, fewer studies have tested for plasticity in the visual system, a surprising detail since courtship and mate choice are

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largely dependent on visual signals across taxa. We used behavioral, gene expression, neural activation, and electrophysiology techniques to test for reproductive state-dependent plasticity in the eye of the cichlid fish *Astatotilapia burtoni*. Males court ovulated females more intensely than gravid females, and ovulated females were behaviorally more responsive to male courtship than gravid females. Using electroretinography to measure visual sensitivity, we found that gravid females had greater visual sensitivity at wavelengths corresponding to male courtship coloration compared to non-reproductively-receptive females. Hormonally-inducing ovulation further increased female's spectral sensitivity compared to pre-injection measurements in gravid females only, suggesting an ovulation-triggered increase in visual sensitivity. Ovulated females had higher mRNA expression levels of neuromodulatory receptors (e.g sex-steroids; gonadotropins) in the eye than nonovulated females, and female affiliative behaviors positively correlated with expression of gonadotropin system receptors in the eye. We also compare how opsin levels in the eye vary with reproductive state in males and females. Collectively, these data provide crucial evidence linking endocrine modulation of visual plasticity to mate choice behaviors in females.

102-8 Button, DJ*; Porro, LB; Barrett, PM; Natural History Museum, London, UK, University College London, UK; *d.button@nhm.ac.uk*

Finite-element modeling of fossil taxa: how close is close enough? Sensitivity analyses on the skull of Megapnosaurus

Finite-element analysis (FEA) is widely-used in paleontology, but accurately modeling extinct taxa is difficult. In particular, properties of sutural tissues are poorly characterized, and modeling them is time-consuming. Validation studies on extant taxa indicate suture inclusion may have little impact on overall strain patterns. However, these have mostly been performed on mammals, whose box-like skulls are unlike those of sauropsids, which include many long, overlapping sutures. We present FEA of the skull of the Early Jurassic theropod *Megapnosaurus kayentakatae* which retains many unfused sutures. These include a loose premaxilla-maxilla joint, hypothesized to have either modified local strain transmission, or facilitated passive kinesis, during biting. The

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skull was restored in Avizo, with jaw muscles reconstructed from osteological correlates. FEA models were built in Strand7, with material properties based on extant analogs. Models were solved with and without sutures for unilateral and bilateral bites along the toothrow. Model comparison shows that including sutures yields significant differences in absolute magnitudes of stress and strain in the skull of *Megapnosaurus*. Further, the loose premaxilla-maxilla articulation redistributes local strains, but high bending stresses in the nasals prevent kinesis. Nonetheless, global comparison reveals that sutures have little impact on overall patterns of relative stress and strain distribution. Consequently, if relative performance is of interest, excluding cranial sutures is a reasonable compromise, but fine-scale information will be lost. This highlights the importance of considering research questions thoroughly before designing model complexity.

S10-1 Byron, ML; Murphy, DW*; Santhanakrishnan, A; Penn State University, University of South Florida, Oklahoma State University; *mzb5025@psu.edu*

Introduction to the symposium

Decades of research on the fluid dynamics of individual appendages and propulsors have increased our overall understanding of flying and swimming. However, investigating the fluid dynamics of coordinated appendages sequentially beating in a metachronal pattern can require different approaches and frameworks, since fluid structures can synergistically interact to produce forces that could not be predicted from each appendage alone. This tactic is used by a large number of invertebrate animals (including crustaceans, polychaetes, ctenophores, and insect nymphs) during a variety of functional behaviors (e.g. swimming, feeding, and pumping). Because these animals are so dissimilar in other ways, there has been no prior opportunity for researchers to come together to discuss the salient commonality of metachronal motion. The purpose of this symposium is to bring together the heretofore disparate community of researchers working on the fluid dynamics of coordinated appendages in order to begin building a cross-specific and cross-disciplinary knowledge base. Speakers and attendees include biologists, engineers, and mathematicians from all career stages, working on a wide variety of model systems. The overall

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goal of the symposium is to establish a multifaceted foundation for what will become a robust and thriving community centered on metachronal swimming and pumping.

92-11 Cabiguin, MM*; Meñez, MAJ; Marine Science Institute University of the Philippines QC, PH; *mcabiguin@msi.upd.edu.ph*

Winners versus losers: reproductive characteristics of a nonnative and native mussel species in Bolinao, Pangasinan, Philippines

Mytella charruana a native mussel species found in South America, Atlantic and Pacific coastlines. Recently, this species was observed to co-occur with a native mussel *Perna viridis*, in Bolinao, Pangasinan, Philippines. Nonnative mussels in novel environments may pose a threat to native mussels since they can compete for food and space. One way of assessing which species may dominate and persist over time is by comparing the reproductive parameters of both natural populations exposed to the same local environmental conditions. This was conducted through monthly sampling per mussel species in experimental mussel lines in traditional culture area of *P. viridis*. The size frequency distribution of both populations was compared over time to determine timing of recruitment. Samples per size frequency was dissected to determine size at sexual maturity and sex ratios. Initial results showed that spats of *M. charruana* was highest during the month of June while spats of *P. viridis* were highest in July. Dissected samples showed that *M. charruana* matures earlier (9mm) compared to *P. viridis* (11mm). Since *M. charruana* recruit first, it could limit the space available for of *P. viridis* to settle and grow. If growth, survival rates and reproductive period of *M. charruana* is higher over time, this could give it a competitive advantage over *P. viridis*. Further studies determining physiological resilience to the seasonal variability as well as changing environmental conditions associated with climate change will be essential to evaluate the ecological and economic impacts of *M. charruana* in Bolinao, Pangasinan and other recently reported areas i.e. SE Asia.

1-10 Cabrera-Cruz, SA*; Larkin, RP; Gimpel, ME; Gruber, JG; Buler, JJ; University of Delaware, Newark, DE, University of Illinois,

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Champaign, IL, Washington College, Chestertown, MD, Washington College, Chestertown, MD; *scabrera@udel.edu*

Do ground-based, downward-facing artificial lights affect the flight behavior of nocturnally migrating birds?

Artificial lights at night (ALAN) have multiple effects on night-migrating birds due to positive phototaxis. Flight paths of migrating birds can be curved or circular rather than straight near bright beams of light aimed skywards, and near lights on communication towers. ALAN installations like these, however, are uncommon. For example, luminaries on communication towers account for ~0.1% of outdoor lighting in the US, while parking lights account for >30%. To test whether ground-based, downwards-pointing lights also affect the flight behavior of migrating birds, we installed three LED spotlights (22000-Lumen each) pointing ~45° downward on top of 5m poles in a dark, sparsely lit rural landscape. We turned these lights on and off sequentially throughout three consecutive bird migration seasons. During ~70 nights we collected >1800 high-resolution 3D flight paths, up to 5km long, of free-flying nocturnally migrating birds using a tracking radar. We predict that low flight altitudes and proximity to our downcast experimental lights relate to a greater probability of behavioral reactions during flight. Nocturnal migrants in North America overfly cities and many other areas with widespread downcast lights. This work will inform us if the most common but often dismissed ALAN installations affect the flight behavior of nocturnally migrating birds.

84-12 Cadney, MD*; Schwartz, NL; Schmill, MP; Castro, AA; McNamara, MP; Hillis, DA; Garland, TJR; Univ. of California, Riverside, UCR; *mcadn001@ucr.edu*

Early post-natal maternal effects on voluntary physical activity, exercise physiology, and associated traits in mice

During the suckling period, mammals progress through critical periods for the central nervous, musculoskeletal, and cardiovascular systems. As a result, various aspects of maternal behavior and physiology can affect offspring in ways that have lasting effects. We tested for possible maternal effects on adult physical activity and exercise physiology using one of 4 replicate lines of mice that have been selectively bred for ~90 generations

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for high voluntary wheel-running behavior (High Runner; HR) and one of 4 non-selected Control (C) lines. Adult HR mice run ~3-fold the daily distances of C mice and have evolved various other differences associated with exercise capacity, including elevated maximal aerobic capacity (VO2max). At birth, we cross-fostered offspring to create 4 experimental groups: C pups to other C dams, HR pups to other HR dams, C pups to HR dams, HR pups to C dams (all individuals were fostered). Mice were weaned 3 weeks later and adult testing began at ~6 weeks of age. As expected, adult HR mice weighed less than their C counterparts and females weighed less than males; in addition, mice raised by HR females had reduced body masses. Also as expected, adult HR mice ran approximately 3-fold more than their C counterparts and females ran more than males, but fostering did not statistically affect running. Similarly, with body mass as a covariate, HR mice had higher VO2max than C, and males had higher VO2max than females, but fostering did not affect running. With body mass as a covariate, both triceps surae muscle mass and liver mass had a 3-way interaction. Analyses of home-cage activity, food consumption, body fat, and other organ masses are in progress. NSF DEB-1655362 to TG.

28-11 Cahill, AE*; Rollinson, EJ; Corona-Avila, I; Ferrero, K; Holmer, K; Mayo, P; Deecher, E; Billman, B; Siryani, N; Biology Department, Albion College, Department of Biological Sciences, East Stroudsburg University, Department of Entomology, Penn State University - and - Department of Biological Sciences, East Stroudsburg University; *acahill@albion.edu*

Abundance and genetic variation in populations of the introduced milkweed aphid in eastern North America

Aphis nerii, the oleander or milkweed aphid, is a widespread introduced species in North America. In the northern part of their introduced range, they specialize on milkweed plants. The species is obligately parthenogenetic and can quickly reach high densities, leading to speculation that aphids may lead to a decline in milkweed quality. Parthenogenesis is also expected to lead to low spatial genetic variation, a pattern supported by previous research. However, aphids do not overwinter in northern populations, which are therefore recolonized every year. Little is known about the geography of recolonization, and this pattern might

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produce patterns of genetic variation that are stronger temporally than spatially. We measured aphid density and plant traits in Michigan and Pennsylvania and found a positive relationship between aphid number and leaf number. However, there was no clear relationship between monarch caterpillars (which were rare in both locations) and aphids. To test predictions of low genetic diversity, we collected individuals in both regions and sequenced them using the COI gene. We found low spatial genetic diversity, including when comparing Michigan and Pennsylvania, as predicted by the aphids' clonal lifestyle. We did detect changes between years, as expected given the recolonization pattern of *A. nerii*. Together, the results present a picture of aphid ecology and genetics on a regional scale.

29-6 Cai, L*; Arnold, B; Xi, Z; Khost, D; Patel, N; Hartmann, C; Manickam, S; Sasirat, S; Nikolov, LA; Mathews, S; Sackton, T; Davis, CC; Harvard University, Sichuan University, University of Connecticut, University of Malaya, Queen Sirikit Botanic Garden, University of California Los Angeles, Louisiana State University; *limingc@ucr.edu*

Deeply altered genome architecture in the iconic endoparasitic flowering plant Rafflesiaceae

Despite more than two-thousandfold variation in genome size, key features of genome architecture are largely conserved across flowering plants. Parasitic plants have elucidated the many ways in which genomes can be modified, yet we still lack comprehensive genome data for species that represent the most extreme form of plant parasitism. Here, we report the genome of the endophytic parasitic angiosperm *Sapria himalayana* Griff. (Rafflesiaceae), which lacks a typical plant body and challenges several fundamental assumptions of plant genome conservation. 44% of the genes conserved in eurosids are lost in *Sapria*, dwarfing any previously reported level of gene loss in vascular plants. These losses demonstrate remarkable functional convergence when compared to other parasitic plants, suggesting a common genetic roadmap underlying the evolution of plant parasitism. Meanwhile, at least 1.2% of the *Sapria* genome, including both genic and intergenic content, is inferred to be derived from host-to-parasite horizontal gene transfers (HGTs) and includes genes potentially adaptive for

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parasitism. Focused phylogenomic reconstruction of these HGTs reveal a hidden history of former host-parasite associations involving close relatives of their modern hosts in the grapevine family. Our findings offer a unique perspective into how deeply angiosperm genomes can be altered to fit an extreme form of plant parasitism. These results also demonstrate the utility of HGTs as DNA fossils to investigate extinct symbioses.

28-2 Calhoon, JA*; Dobkowski, K; Bates College; *jcalhoon@bates.edu*
Feeding preferences of red sea urchins (Mesocentrotus franciscanus) in the Salish Sea
In the Salish Sea, red sea urchins *(Mesocentrotus franciscanus)* are influential herbivores in subtidal ecosystems. They consume a variety of macroalgae but often prefer *Nereocystis luetkeana* . These urchins may play a vital role in regulating the macroalgae composition of the ecosystem, however *Sargassum muticum* has become an influential presence in the ecosystem, possibly competing with local macroalgal species growing around the Salish Sea. It has not yet been established how the presence of *S. muticum* affects the feeding behavior of *M. franciscanus* and if they will consume this common, but non-native, species. In this study I investigated this relationship and found that the urchins will feed on *N. luetkeana* over *S. muticum* but will consume *S. muticum* when there is no other choice. If *S. muticum* continues to spread throughout the Salish Sea, the feeding preferences of *M. franciscanus* will likely compound the competition between *S. muticum* and *N. luetkeana* adversely affecting the native species.

S7-8 Camacho, E*; Anglero-Rodriguez, Y; Smith, DFQ; Jacobs, E; Dong, Y; Cordero, RJB; Dimopoulos, G; Casadevall, A; Bloomberg School of Public Health, Johns Hopkins University, Baltimore, MD , Bloomberg School of Public Health, Johns Hopkins University, Baltimore, MD; *ecamach2@jhu.edu*
Parallels of melanization in Cryptococcus neoformans and Anopheles gambiae
Melanins are natural pigments synthesized by organisms in all biological kingdoms. In fungi, melanins are components of the cell wall that provide protection against biotic and abiotic elements.

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In insects, these biopolymers are essential on wound healing and innate immunity. Melanin biosynthesis in both fungi and insects is mediated by a phenoloxidase that catalyzes the oxidation of phenolic substrates. A better understanding of the chemical nature of melanin and its role in critical physiological processes of malaria-transmitting mosquitoes is highly valuable to the development of novel biocontrol strategies. In this study, we used spectroscopy, high-resolution microscopy, proteomics, and biochemical methodologies to analyze mosquito melanin involved in immune defense (melanotic capsules) and structural barriers (cuticle). Our data showed that *A. gambiae* melanotic capsules are characterized by signature properties of eumelanins closely associated with proteins. Furthermore, we observed that a polyphenol diet reduces susceptibility to the human malaria parasite and enhances cuticular pigmentation and heat absorption. These features are remarkably similar between fungi and insects melanization that highlight a functional importance for melanins in the evolution of life.

102-3 Camp, AL; University of Liverpool, UK; *ariel.camp@liverpool.ac.uk*

Rainbow trout use 3D vertebral flexion during suction feeding

The intervertebral joints (IVJs) of fish were initially viewed as hinges that only allowed lateral flexion, and most studies of their motion and mechanics have focused on 2D flexion during swimming. But in feeding many fish dorsally rotate the neurocranium, elevating it relative to the body to expand the mouth cavity. Cranial elevation requires dorsal flexion of at least the cranio-vertebral joint, and likely some IVJs. It is unknown which IVJs contribute to cranial elevation because dorsal flexion of these joints is challenging to measure. I used X-ray Reconstruction of Moving Morphology (XROMM) to measure 3D motion of the neurocranium and anterior 24 vertebrae in Rainbow Trout, *Oncorhynchus mykiss*, during feeding (28 strikes, 3 fish). Trout used forward swimming and suction to capture food pellets, with maximum cranial elevation ranging from 2 to 18 degrees (measured as dorsal rotation of the neurocranium relative to a body plane). Lateral flexion was highly variable during cranial elevation, depending on the swimming behavior, and occurred across the IVJs. The vertebral column also

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flexed dorsally as the neurocranium elevated. Dorsal flexion extended beyond the cranio-vertebral joint as expected, but the magnitude varied across the IVJs. At maximum cranial elevation, the magnitude of dorsal flexion usually increased rostrocaudally over the first 8 IVJs, then decreased to reach a minimum around the 11th postcranial IVJ. Dorsal flexion over the remaining caudal IVJs was variable and usually lower magnitude. Thus, a substantial region of anterior IVJs flexed dorsally and laterally in trout, although not all IVJs appeared to contribute equally to cranial elevation. These data provide a new perspective on the functional and evolutionary morphology of the vertebral column in fish.

44-7 Campbell, M*; Alderman, S; Van Der Kraak, G; Trent University, University of Guelph; *micampbell@trentu.ca*

The effects of ethinylestradiol on estrogen-regulated neurogenic pathway in adult zebrafish (Danio rerio)

While previous studies have demonstrated the presence of estrogenic compounds in waste water effluent, there is limited knowledge of how these compounds impact the regulatory pathways of the brain in mature fish. These studies illustrated that fish exposed to exogenous estrogens exhibit decreased proliferation of the brain and elevated expression of aromatase B (cyp19a1b) and estrogen receptor 2b (esr2b). In this study, male zebrafish (n=12) were exposed to exogenous ethinylestradiol (EE2), at environmentally relevant concentrations (0, 2.5, and 25 ng/L), for seven-days, to examine its effect on the regulatory pathways which controls neural progenitors proliferation in the hypothalamus and telencephalon. The liver of each fish was examined for changes in the expression of vitellogenin (vtg), to confirm that the EE2 was taken up by the fish at levels that would upregulate vtg expression. Changes in the estrogen regulated proliferation pathway were monitored via the expression of esr2b, cy19a1b, and proliferating cellular nuclear antigen (pcna) (n=8). Although liver vtg expression was significantly upregulated when exposed to the high treatment, no differences in the expression of cy19a1b, esr2b, or pcna in the brain were detected. The lack of change in proliferation, noted by differences in the expression of pcna between treatments is predicted to be due to EE2 not effecting the expression of cy19a1b and esr2b, which control early steps of the regulatory pathway.

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Estrogen regulated pathways are an important part of the physiology of brains and should be examined further in case higher concentrations can induce proliferation of the brain by impacting cyp19a1b and esr2b expression.

BSP-10-6 Camper, BT*; Friedman, ST; Wainwright, PC; Price, SA; Clemson University, University of California, Davis; *bcamper@g.clemson.edu*

Evaluation of body size and shape variation across latitude in teleost fishes

Bergmann's Rule is an ecogeographical trend describing the tendency in body size to increase towards higher elevations and either high-latitude extreme. This pattern is well-supported intraspecifically in endotherms and is often explained by an underlying negative body size-temperature relationship, driven by heat conservation in colder environments. In contrast, at broader taxonomic scales (i.e., interspecific evaluations) and within ectotherms, evaluations of Bergmann's Rule yield conflicting results. Proposed mechanisms facilitating body size-latitude trends in ectotherms are also more varied, including increased longevity at higher latitudes and cell size variation induced by temperature. Body shape modifications in the surface area to volume ratio may drive the frequently observed positive body size-latitude relationship in endotherms, but body shape variation across latitude has not been well-evaluated in ectotherms. Moreover, body shape is indicative of locomotion, trophic niche, and/or thermoregulatory performance, and selective pressures on these complex traits may systematically differ with latitude. We therefore looked for trends in size and shape associated with latitude and water depth, across 3194 marine species (266 families; 35 orders) of teleost fishes, using a rigorous phylogenetic comparative approach. Shape variables were constructed from linear morphometric measurements of length, depth, and width. Our analyses reveal that shape, but not size, changes systematically with latitude across the full teleost dataset. At higher latitudes fishes are more elongate and wider. A latitudinal cline in fish body shape suggests that body size trends observed in other taxa may only serve as correlates for selective gradients on other morphological features.

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S9-4 Campos, SM; Swarthmore College; *scampos3@swarthmore.edu*
Chemical signals control our social lives: Lessons from lizards
Chemical signals in the body, in the brain, and semiochemicals excreted into the environment control the social lives of animals, impacting reproductive opportunities and competitive outcomes. I use lizards to examine the role of both endocrine and exocrine signals in regulating male-male and male-female interactions from an evolutionary standpoint. Territorial male lizards compete for access to females and other resources and the hormone arginine vasotocin (vasopressin) modulates competitive interactions via the visual sensory system, as demonstrated by the life's work of Walt Wilczynski, but vasotocin may also impact chemosensory behavior during social interactions. Here, I demonstrate how vasotocin impacts chemosensory behavior during male-male interactions in green anole lizards, then compare these data to the impact of vasotocin in females on male-female interactions. I also discuss the future of the field of endocrine modulation of chemical communication in lizards.

48-4 Cantley, JT*; McDonnell, AJ; Branson, J; Kobara, JR; Long, S; Garnett, W; Martine, CT; San Francisco State University, Chicago Botanical Garden, Bucknell University, Wiliwili Native Plants; *cantley@sfsu.edu*
Temperate Eurasian origins of Hawaiian Chenopodium (Amaranthaceae), plus description of a new subspecies endemic to Moloka 'i
Hawaiian taxa of *Chenopodium* are tetraploids and are distinguished from other members of the circumglobally distributed genus byminute morphological characters. Because of these reasons, the geographic origin of Hawaiian *Chenopodium* has remained unclear. Across the Hawaiian Archipelago, taxa of *Chenopodium* are morphologically variable and grow in highly disparate xeric habitats, especially in terms of precipitation, temperature, wind, salt spray, and solar irradiation. Habitats include dry subalpine shrublands, sandy beach strands on atolls in the Northwest Hawaiian Islands, dry to mesic forests, and precipitously tall sea cliffs of northwestern Moloka 'i. From the Moloka 'i sea cliffs, we describe *C.*

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oahuense subspecies *ilioensis* as segregated from the widespread Hawaiian *C. oahuense* sensu lato. Morphometric analyses distinguish *C. oahuense* subsp. *ilioensis* by its strongly prostrate to scandent habit, thick succulent leaves, smaller average leaf size, limited lobing of the laminar margins, and smaller seeds. Phylogenetic analyses using two DNA regions (the plastid gene rpl32-trnL and nuclear ITS) of newly sequenced individuals of *C. oahuense* s. l. and *C. oahuense* subsp. *ilioensis* plus outgroup taxa support the monophyly of Hawaiian *Chenopodium* and reveal a geographic origin of temperate Eurasia. Two equivocal hypothetical scenarios are discussed regarding the likely sequence of events leading to the arrival of *Chenopodium* in Hawaiian Islands followed by possible in situ speciation of the Moloka ʻi endemic *C. oahuense* subsp. *ilioensis*. This presentation will include an update of ongoing physiological and genomic projects.

98-12 Capano, JG*; Kaczmarek, EB; Lomax, JJ; Turner, ML; Brainerd, EL; Ryerson, WG; Brown University, Providence, RI, Brown University, Saint Anselm College, Manchester, NH; *john_capano@brown.edu*

Reticulated pythons roll their hemimandibles and splay their quadrates to engulf enormous prey

Macrostomy in snakes enables these gape-limited predators to swallow enormous prey that have large cross-sectional areas. This is permitted by the combination of their extensible soft tissues and highly kinetic cranial skeletons. Although previous studies hypothesized how cranial bones displace during ingestion, no direct measurements have been made. We used XROMM to quantify motions of the braincase, maxilla, palatines, pterygoids, quadrates, and hemimandibles during intraoral prey transport in reticulated pythons, *Malayopython reticulatus*. We confirmed previous hypotheses that the ipsilateral maxilla and palatopterygoid jaw operate as a functional unit to anchor the braincase during contralateral protraction. We found that maximal gape and mandibular advancement were associated with substantial pitch (elevation), substantial yaw (protraction), and moderate roll (long-axis) rotations of the quadrate. Our data confirmed other hypotheses of moderate yaw rotation between the dentary and compound of each hemimandible. Similar to previous studies, we also found large long-axis

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rotations of the hemimandibles during advancement, which disengage the teeth from the prey. These roll rotations then reversed to re-engage the toothrow and grasp the prey before contralateral advances. We hypothesize these rotations prevent tooth engagement during hemimandible swings and reduce ingestion time. We unexpectedly found that, during hemimandible roll, the saddle joint between the quadrate and mandible dislocated, with displacements greater than 10 millimeters. These data suggest that hemimandibular long-axis rotations may be more ubiquitous than assumed within vertebrate feeding mechanisms and integral to the evolution of macrostomy in snakes.

2-2 Caplins, SA; University of California, Davis; *sacaplins@ucdavis.edu*

Evolve and resequence for egg size in a sea slug with striking life-history plasticity

Developmental mode consists of suites of phenotypic and behavioral traits that can influence micro- and macro-evolutionary patterns and processes including gene-flow, local adaptation, and speciation and extinction. In marine invertebrates there are typically two discrete types of developmental mode: large non-feeding, non-dispersive lecithotrophic larvae and small feeding and highly dispersive planktotrophic larvae. A few species exhibit intraspecific variation for developmental mode (termed poecilogony) and provide powerful systems to identify the minimum number of genetic changes and environmental influences that underlie developmental mode evolution. I used an evolve and resequence approach to identify the genomic response to selection for increased proportions of lecithotrophy in the poecilogonous sea slug Alderia willowi. Lecithotrophy increased from 36% to 60-70% after 5 generations of selection in low (16 ppt) and high salinity (32 ppt) across 6 replicate populations. In a genome-wide test of association I found 10 loci on 8 scaffolds to be associated with developmental mode, showing the polygenic nature of developmental mode in A. willowi. Sequencing the replicate lines after selection I found a significant change in allele frequency for these loci that was shared across replicate lines. These results show that there is standing genetic variation for developmental mode in A. willowi that may be maintained via phenotypic plasticity.

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BSP-8-8 Capshaw, G*; Soares, D; Christensen-Dalsgaard, J; Carr, CE; University of Maryland, College Park, New Jersey Institute of Technology, University of Southern Denmark, Odense; *gcapshaw@umd.edu*

Directional hearing in salamanders

The evolution of the vertebrate auditory system, prior to the development of acoustic communication, was driven to enhance the detection of biologically relevant sounds within the environment and to associate them with their source in order to construct an auditory scene of their surroundings. The ability to localize sounds confers a clear fitness advantage for species that can use acoustic cues to facilitate navigation within a complex environment, detect prey, and avoid predators. In many terrestrial species, the tympanic middle ear is a key sensory feature enabling the encoding of directional cues from sound sources; however, fossil evidence reveals a delay between the water-to-land transition and the emergence of tympanic middle ears during which the ancestral tetrapod ear was largely unspecialized for terrestrial hearing. Inherently directional otolithic ears emerged early in vertebrate evolutionary history, however, indicating that peripheral encoding of directional acoustic cues may be an ancestral feature of the tetrapod auditory system. Here, we used atympanic salamanders to test the hypothesis that extratympanic mechanisms for hearing are sufficient to confer directionality in a terrestrial environment. We performed auditory brainstem response recordings to investigate the peripheral encoding of directional information in the auditory nerve from free-field sound pressure stimuli. We combined these measurements with laser vibrometry to assess the contributions of bone conduction mechanisms for directional hearing in these atympanic species.

57-3 Cárdenas-Posada, G*; Iwaniuk, AN; Fuxjager, MJ; Brown University Providence, RI/Wake Forest University Winston-Salem, NC, University of Lethbridge, Alberta, Canada, Brown University Providence, RI; *cardg16@wfu.edu*

Brain size evolution precedes innovations in foraging strategy among woodpeckers

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Understanding the correlated evolution of brain size and behavior has interested biologists for decades. Many studies have investigated the relationship between brain size and behavior, but the majority of these, are correlational and therefore do not test whether evolutionary changes in brain size precede behavior, or vice versa. Here we address this gap by using phylogenetic generalized least squares (PGLS) regression to test for associations between brain size and foraging tactics in woodpeckers. We then explore various evolutionary scenarios through discrete trait modeling and reversible jump Markov chain Monte Carlo (rjMCMC) analyses. This last method allowed us to estimate evolutionary timelines by assessing likelihoods of certain evolutionary transitions between states of binary traits. We show that woodpecker species that rely heavily on extractive foraging techniques, specifically those that feed on wood-boring larvae from trees, have a larger brain relative to body size. Moreover, extractive foraging and brain size coevolve, such that the ability to feed on these larvae only arises in species that retained an ancestral large brain. Thus, larger brains 'evolve first' and could provide the computational capacity needed to evolve extractive foraging behavior and occupy new ecological niches.

55-9 Carr, EM*; Cohen, KE; Summers, AP; University of South Florida, Friday Harbor Labs, University of Washington; *emilycarr1@mail.usf.edu*

The fate of tooth replacement in Pacific Lingcod (Ophiodon elongatus) with pulse-chase experiments

Tooth replacement is difficult to assess in polyphyodont vertebrates, but we used a pulse-chase technique to track tooth replacement rate and location in oral and pharyngeal jaws. Pacific Lingcod (*Ophiodon elongatus*) were immersed in Alizarin Red S dye for 12 hours, then maintained in flow-through seawater for 2-10 days, and finally put in calcein dye for 12 hours. We used fluorescence microscopy to reveal which teeth had both red and green dye and which had only green dye; fluorescent green teeth were newly replaced, and teeth with red or a combination of red and green fluorescence predated the Alizarin treatment. The average replacement rate across the dentary, premaxilla, vomer (palatine included), and upper and lower pharyngeal jaws was determined to be

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3.6% per day. Replacement rate was significantly higher in the lower pharyngeal jaw, leading to the hypothesis that feeding was a driver of tooth replacement. However, when a similar 10 day pulse-chase experiment was repeated for two groups of feeding and non-feeding specimens there was no significant difference between the replacement rates. We found that lingcod teeth have a size and location fate; smaller teeth at a certain jaw position will not grow to replace larger teeth at another position. This was determined by the presence of large green teeth (new) next to large red teeth (old) in one position of the jaw, while other red teeth in a different position remained small. We also found increased rates of replacement at the anterior of the lower pharyngeal jaw relative to the posterior. This leads to an appearance of more wear on posterior teeth. We propose that teeth are not moving from front to back on pharyngeal jaws, but the appearance of this motion is due to differential replacement.

59-7 Carrasquillo, AL*; Crawford, DL; Oleksiak, MF; University of Miami Rosenstiel School of Marine and Atmospheric Sciences; *alc251@miami.edu*

Heritability of critical thermal maximum temperature in Fundulus heteroclitus

Global climate change caused by human activity over the course of the last hundred years has altered our natural environment. One of the largest anthropogenic changes is increase in temperature. These anthropogenic increases in temperature, may require animals to adapt to be more tolerant to heat stress. This adaptation requires heritable variation in phenotypic traits that mitigate the effect of increase in global temperature. One trait of susceptibility to heat stress is critical thermal maximum temperature (CTmax). CTmax is measured as the temperature at which an animal displays loss of equilibrium. CTmax is a phenotype that has been found to be highly variable in *Fundulus heteroclitus* a species of brackish killifish, however, there have been no published measures on the heritable this trait is in this species. These data are important because they will give us insight into how fish species will change as environmental temperatures increase. To quantify the heritability of CTmax, individuals with highest and lowest CT Max will be selectively bred. These selected offspring will be raised until

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they are mature and then tested for CTmax. Narrow sense heritability (H^2) is determine by the response (ΔR) to this selective breeding (S) as defined by the breeder's equation $R=h^2S$. To determine heritability, this equation will be used.

102-4 Carter, AM*; Johnson, EH; Hsieh, S-T; Dodson, P; University of Pennsylvania, Philadelphia, Cornell University, Ithaca, Temple University, Philadelphia; *caja@seas.upenn.edu*

Range-of-motion in dorsal vertebra of ancient tetrapods

Ancient tetrapods evolved a diverse array of complex vertebrae 360 million years ago. These complex vertebrae—composed of separate non-fused elements, or persistent notochords—were ubiquitous in every major stem tetrapod lineage. Nevertheless, paleobiologists have struggled to come to a consensus on the role of complex vertebrae on single vertebral joint range-of-motion (ROM), and in turn, overall spinal flexibility. This disagreement is in part due to the difficulty of modeling multipartite forms. Additionally, only three families of extant animals (Lacertidae, Xantusiidae, Gekkonidae) have complex vertebrae, the homology of their vertebral elements, and applicability as modern analogs to understanding stem tetrapod vertebrae remain unknown. However, with advances in 3D digital modeling and printing, modeling complex vertebrae with fidelity are now possible. To estimate vertebral ROM and passive stiffness in ancient tetrapods, we used both 3D virtual models and printing to investigate the form-function relationships of single intervertebral joints in five well-preserved and understood ancient tetrapods. These taxa represent different habitats, vertebral forms, and maximum sizes. We hypothesized that multipartite vertebrae would have greater ROM than taxa with fused elements but persistent notochords(monospondylous). Contrary to expectations, we found complex vertebrae have smaller ROM than monospondylous vertebrae. Conversely, we find stiffness is related to habitat, not vertebral composition. Finally, our results showed linear and angular measurements that are correlated with vertebral ROM in extant taxa are not correlative in our Permian taxa, demonstrating a need for more empirical studies.

30-6 Casbourn, GW*; Posliff, C; Henry, C; MacDougall-Shackleton, E;

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MacDougall-Shackleton, S; University of Western Ontario, London; *gcasbour@uwo.ca*

The role of testosterone in regulating the movement behaviours of juvenile migrant songbirds

The post-fledging period is a critical stage in the life of a juvenile migrant songbird. Juveniles must develop their foraging skills, as well as the flight, navigation, and orientation skills that will allow them to make their first migration. Movement across the landscape is critical to developing all of these skills, and there is likely individual variation in the propensity to move. Testosterone is related to individual differences in migration distance in adult sparrows, but it has not been studied in the context of other movement behaviours. This study used juvenile Song Sparrows (*Melospiza melodia*) to investigate the relationships among movement propensity in a novel environment, juvenile prospecting movements, and testosterone profile. Testosterone profile is here defined as the maximal level of circulating testosterone produced in response to an injection of GnRH. We introduced fledged, free-living juvenile birds to an artificial chamber (2.4 x 2.4 x 1.8 m) containing 5 artificial trees, and recorded activity for 10 minutes as an index of exploration behaviour. Following this, we injected birds with GnRH to trigger a surge in circulating testosterone, and collected blood samples 30 minutes post-injection. Finally, we radiotagged birds for 2-4 weeks to assess prospecting movements. Our findings will thus test for a relationship between individuals' movement/exploration propensity within a novel environment and on the natal landscape, and individual regulation of testosterone.

19-7 Cavagnaro, JW; Arizona State Univerity; *geicothetoad@aol.com*

Can fluorescence in reptiles and amphibians have a visual signalling function?

Recent reports from diverse taxonomic groups have made it clear that biofluorescence is widespread in terrestrial vertebrates. It is often presumed that this fluorescent coloration has a visual signalling function, however this hypothesis is not well supported by behavioral experiments or visual models, especially in reptiles and amphibians. The striking glow of these animals under intense UV illumination is misleading, as in natural lighting conditions the low relative proportion of UV wavelengths means that fluorescent

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emissions will generally be overwhelmed by reflected light and thus not visible. By modelling gecko perception of fluorescent color patches measured with and without sunblock, I show that the fluorescent emissions of the palmatogecko, *Pachydactylus rangei*, are imperceptible to conspecifics when viewed in daylight. I also describe previously unreported fluorescence from ten species of reptile and one amphibian, primarily from the Namib desert of Namibia and Angola. There is a notable correlation between fluorescent reptile species and desert environments, as well as latitude. Finally, I propose alternative hypotheses for the function of external biofluorescence in reptiles and amphibians, including UV absorbance and light sensing.

20-6 Caves, EM*; Johnsen, S; University of Exeter, Penryn, UK, Duke University, Durham NC, USA; *e.m.caves@exeter.ac.uk*

The sensory impacts of climate change: Bathymetric shifts and visually-mediated interactions in aquatic species

Animals use color in contexts ranging from mate choice to prey detection to mutualistic partner choice. Color perception is a function of the reflectance of a colour patch, the optical properties of the medium, the viewer's visual system, and the ambient illumination spectrum. In aquatic environments, ambient illumination is dependent upon both depth and the optical properties of the water, both of which can be altered by anthropogenic processes. Many aquatic species have shifted deeper in response to warming surface waters (known as bathymetric shifts) at rates as high as 2 m/year, and dissolved and particulate compounds are increasing in many bodies of water. Changes in water color due to increased turbidity are well-described and can affect interactions mediated by color signals. Bathymetric shifts can result in similarly large changes to a species' optical environment, but no studies have yet focused on how bathymetric shifts may impact visually-mediated interactions. Here, we draw attention to a potential link between changes in temperature and in an organism's visual world. We synthesize information on color vision, optical environments in aquatic habitats, and signal coloration. We discuss (1) the conditions under which bathymetric shifts may impact color signaling; (2) what interactions might be affected by bathymetric shifts; and (3) how organisms might respond

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to these changes. As oceans warm, and temperature fluctuations grow more extreme, many species may be forced into deeper waters. Such shifts can affect an organism's visual world, thus interfering with a variety of behavioral processes, with important consequences for fitness, population dynamics, and community structure.

100-3 Cavigelli, SA*; McMahon, EK; Farhan, S; Pennsylvania State University; *sac34@psu.edu*

Consistency of behavioral phenotypes and underlying physiology

Behavioral phenotypes (BP) (personality, temperament) can be relatively consistent within an individual over time and across situations, and BPs can predict individual fitness and survival. Several BPs have been identified, for example, some individuals are reliably more exploratory, bold, active, or social than others. While much research has characterized these BPs in different species, their relative consistency across time and situations, and the physiology that may drive their consistency is not well understood. The objectives of this study were to determine relative consistency of BPs across different situations and time, and to determine associations of BPs with physiological processes. To measure BPs, we used 3 different behavioral tests (Novel Social Arena, Novel Object Arena, Partner Preference Task), each conducted three times with 54 Sprague-Dawley rats. To assess physiological processes, we measured glucocorticoid (GC) responses to acute restraint, innate immune responses to lipopolysaccharide, and adaptive immune responses to keyhole limpet hemocyanin. Results indicate that Social Boldness and Activity behaviors were individually consistent across tests and time, whereas Exploration behaviors were less consistent. Of the different physiological responses, GC responses were most frequently associated with BPs. Social Boldness and Exploration were associated with lower stress-induced GCs and enhanced innate immune responses, whereas Activity was associated with elevated GC reactivity, elevated basal pro-inflammatory circulating cytokines, and lower innate immune reactivity. The results indicate that certain behavioral phenotypes are more consistent across time and situations than others, and that underlying physiology may partially drive BP consistency. This line of research requires further investigation.

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BSP-2-3 Cellini, B*; Mongeau, J-M; The Pennsylvania State University; *boc5244@psu.edu*

The critical influence of head movements on wing steering responses in fly flight

Many animals move their eyes to direct and stabilize gaze. In flight, insects stabilize gaze via a pattern of head and body movements, yet their interaction remains unclear. We used a control theoretic framework to study how head and wing movements are coordinated and quantified how head movements shaped visual inputs in tethered fruit flies. Head movements reduced retinal slip error by up to 60%, slowing down visual inputs. Head movements responded to the visual stimulus in as little as 10 ms—which was more than four times faster than wing movements—suggesting a temporal order in the flow of visual information such that the head filters visual information which then elicits downstream wing steering responses. By comparing the responses of head-free and head-fixed flies, we revealed that head movements increased the strength of downstream wing steering efforts and improved coordination between the wings and visual stimulus. Fixing the head of flies had a detrimental effect on flight performance, decreasing wing gain, flapping frequency, and overall thrust, thus reducing the total mechanical power generated by the flight motor. To reveal how head movements modulate visual inputs entering the brain, we simulated an Elementary Motion Detector on a moving "head". Head movements shifted the effective visual input dynamic range onto the sensitivity optimum of the motion vision pathway, allowing flies to encode visual motion speeds two times faster than previously thought. Overall, our findings reveal the critical role of active vision in insect flight control.

BSP-8-6 Chai, CM*; Wen, C; Wong, WR; Park, HN; Cohen, SM; Sternberg, PW; Caltech; *cchai@caltech.edu*

Discovery of a highly-conserved behavioral role for an interneuron neuropeptide receptor

Throughout the animal kingdom, neuropeptide signaling mediates many survival-promoting behaviors including foraging and the escape response. Even in traditional model organisms like *Caenorhabditis*

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elegans, however, the expression and function of several neuropeptide G-protein coupled receptors (GPCRs) remain uncharacterized. Here, we combine molecular genetics and high-throughput behavioral screening to reveal a novel conserved behavioral role for the nematode interneuron neuropeptide receptor FRPR-14. We systematically screened 21 CRISPR/Cas9-generated putative GPCR null mutants using two behavioral paradigms, the posterior light touch-induced response and freely-moving locomotion tracking assays. Although a third of mutants had at least one phenotype, only the *frpr-14* mutant was defective in both. A *frpr-14* GFP reporter was expressed in the AVJ and AIB interneurons, both of which are presynaptic to several command interneurons. However, only AVJ-specific *frpr-14* cDNA expression was sufficient to rescue the full repertoire of mutant phenotypes. We next applied a comparative approach by studying the homologous *Cbr-frpr-14* in *Caenorhabditis briggsae*. A *Cbr-frpr-14* GFP reporter showed expression in a single pair of interneurons with strikingly similar morphology and relative anatomical position as the *C. elegans* AVJ neurons. While *C. elegans* AVJ-specific expression of *Cbr-frpr-14* cDNA rescued all mutant phenotypes, a putative *Cbr-frpr-14* null mutant was only defective in the posterior light touch-induced response. We conclude that although FRPR-14's function at the cellular level is evolutionarily-conserved, this is less evident at the organismal level likely due to differing gene expression patterns and neural architecture between species.

41-13 Challener, RC; Bellarmine University, Louisville, KY; *rchallener@bellarmine.edu*

Teaching a women-in-science course: lessons from a biologist

There are many courses offered to undergraduates on the history of women in the sciences (WIS) and the current conditions and issues that WIS face. It is a timely topic to offer to our students, both male and female, in the Sciences, Technology, Engineering and Math (STEM) disciplines to increase their awareness and understanding of the challenging and celebratory moments WIS have had and will have. Most of these courses, if available, are offered through Gender and Women's Studies departments. The purpose of this talk is to highlight that it is quite possible for a scientist to teach this course and thus to encourage others to offer it at their

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institutions. In the Spring of 2020, I designed and co-taught an Honors seminar on WIS to undergraduate students (n = 15) whose majors were highly diverse (Biology, Biochemistry and Molecular Biology, Psychology, Math, Music, Nursing, and Exercise Science). The course was divided into four sections: the history of WIS, the current issues WIS face, the cultural contexts surrounding WIS and what the future might look like for WIS. Students found the material and diversity of topics highly engaging and relevant to their current and future personal and professional lives. This talk will discuss recruiting co-instructors, syllabus design, and the major 'takeaway' lessons learned from this endeavor. Ultimately, from readings and topics to the size of the class (large or small), there are many options and possibilities for a course of this nature.

23-4 Challita, EJ*; Acharya, R; Krugner, R; Bhamla, S; Georgia Institute of technology, United States Department of Agriculture; *elio.challita@gatech.edu*

Peeing one drop at a time: How sharpshooter insects use superpropulsion to launch their fluid excreta and why

Shaprshooters are sap-sucking insects that use biological springs located at their anal stylus to fling droplet excreta at high speeds and accelerations. Here, we investigate the unique catapulting mechanism used by these insects to eject the fluid drops. Unlike the propulsion of rigid projectiles, where their maximum speed is set by the speed of the underlying actuator, we discover that sharpshooters exploit the elastic properties of water droplets to fling them at 2 to 3 times faster speed than the underlying actuator. We uncover how this 'superpropulsion' is achieved due to a fine tuning between the catapulting frequency of the anal stylus and the Rayleigh frequency of a liquid droplet. Through mathematical modeling and scaling analysis, we outline the biological and physical limits of superpropulsion, in comparison to other fluid pumping techniques. We finally discuss the potential of superpropulsion in engineering applications.

90-11 Chan, JK*; Thornton, JA; Riffell, JA; University of Washington, department of Biology, University of Washington,

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department of Atmospheric Sciences; *jkchan@uw.edu*

Nighttime atmospheric oxidation of floral scent impacts the ability of hawkmoths to locate a floral scent source

Floral scent is important to pollinators for locating flowers as it relays information to pollinators regarding the quality of floral food resources. Pollinators need to track floral scent in a dynamic chemical environment, and these scent signals are vulnerable to interference by degradation in the atmosphere. Nitrate radicals are a dominant atmospheric oxidant at night in human polluted environments, and here we simulate oxidation conditions at 120 ppb ozone and 60 ppb nitrogen dioxide corresponding to a highly polluted industrial environment. We investigate the impact of nighttime nitrate radical atmospheric oxidation on floral scent composition, and how this impacts pollination behavior by the hawkmoths *Hyles lineata* and *Manduca sexta*. Using gas chromatograph mass spectrometry and electroantennographic detection we created an artificial floral scent blend of the primrose *Oenothera pallida* which is pollinated by these hawkmoths in the field. No-choice wind tunnel behavior assays indicate that *Manduca sexta* is attracted to the floral scent blend at a high rate both before and after nitrate radical oxidation, however the time taken to locate the scent source was significantly longer with the oxidized scent due to a delay in the initiation of "cast and surge" scent tracking behavior. Chemical analysis of the atmospheric oxidation of the floral scent blend by nitrate radicals suggests significant changes to floral scent composition after 90 seconds of atmospheric oxidation. Together, these suggest that conditions generated by human air pollution can significantly disrupt pollinator odor navigation, which may impact pollinator services.

95-5 Chandrasegaran, K*; Vinauger, C; Virginia Polytechnic Institute and State University (Virginia Tech), Blacksburg, VA; *karthikeyan@vt.edu*

Deciphering the mechanistic links between larval ecology and host-seeking behavior in mosquitoes

Mosquitoes are important vectors that claim about a million lives every year worldwide by transmitting a range of diseases. As larvae, they occupy diverse habitats and are influenced by a suite of ecological factors that impact their adult life. Interestingly,

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the magnitude of these effects differs between males and females. Female mosquitoes show great plasticity of body size in response to environmental variability. Also, body size in females strongly correlates with their adult behavior and reproductive traits. Here, we varied levels of intraspecific competition to quantify how larval conditions impacted olfactory responses of adult females seeking hosts for blood. The preliminary results suggest that host-seeking preferences are strongly linked to variability in female body size. Analysis of the head transcriptome of large and small-sized females reveals differences in genes linked to the onset of host-seeking and olfactory sensitivity. Using these results, we are pursuing electrophysiological investigations to understand the neural bases of the observed size-dependent variability in mosquito host-seeking behavior. These results will be discussed in the context of mosquito population dynamics and the ensuing disease consequences.

29-4 Chang, ES*; Travert, M; Sanders, SM; Klompen, AML; Gonzalez, P; Barreira, SN; Cartwright, P; Baxevanis, AD; NHGRI/NIH, U. Kansas, U. Pittsburgh; *sally.chang@nih.gov*

Insights from the draft genome assembly for the hydrozoan Podocoryna carnea: Just the tip of the tentacle

Cnidarians are an excellent system for studying the evolution of complexity and novelty given their diversity in body plan organization and life history strategy. Building on the advances made possible by the *Hydractinia* genome sequencing project, we are generating a high-quality genome sequence for the closely related hydrozoan, *Podocoryna carnea* which, unlike *Hydractinia*, has a pelagic medusae (jellyfish) phase. These genomic data will significantly advance comparative genomics studies aimed at identifying the genomic toolkit specific to production of the medusa life cycle stage and its constituent cell types, some of which are stage-specific and potentially convergent to bilaterian cell types such as striated muscle and photoreceptor cells. We will also extend our current studies on allorecognition and sex determination in *Hydractinia* to *P. carnea*, with a focus on whether possessing a pelagic life cycle stage alters the genetic architecture of these processes. Our initial sequencing of *P. carnea* laboratory strains reveals that its genome is highly

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heterozygous, leading us to adopt a trio-binning strategy for assembling a fully phased genome of *P. carnea* by long-read sequencing of an F1 individual and short-read sequencing of both of its parents. The preliminary Illumina assemblies of the parental genotypes and PacBio assembly of the F1 (N50 > 1.5 Mbp) have already proved useful for identification of medusa-specific genes and potential allorecognition sequences. Ongoing improvements to the *P. carnea* genome sequence, along with current and planned stage- and tissue-specific single-cell RNA sequencing efforts, will advance the tractability of *P. carnea* as a model for evolutionary genomics.

63-3 Chang van Oordt, DA*; Taff, CC; Ryan, TA; Vitousek, MN; Dept. of Ecology and Evolutionary Biology, Cornell University; *dac385@cornell.edu*

Context-based costs of innate immunity? Trade-offs between reproductive effort and bactericidal capacity vary with timing of breeding in a migratory bird

Immunity against pathogens comes at an energetic cost and organisms often have to balance investment in immunity with other important processes. For migratory birds, these trade-offs might be especially apparent during the breeding season because of the resources needed for demanding processes like egg-laying or nestling provisioning. We searched for evidence of trade-offs between immunity and investment in costly processes including the corticosterone stress response and reproductive effort and success in a breeding bird. We assayed bacteria killing ability (BKA) of wild female Tree Swallows nesting in boxes, and measured both baseline and stress-induced corticosterone levels. We found no evidence of a trade-off between BKA and the stress response. However, we found that individuals with stronger BKA fed their nestlings at slower rates. Among Tree Swallows, high quality birds breed early in the season, while low quality birds breed later, lay fewer eggs, and fledge fewer young. We found that late-breeding individuals that had stronger BKA laid fewer eggs, while immune capacity was not related to clutch size in early breeders. Despite these differences in reproductive effort, there was ultimately no association between BKA and nestling survival to fledging or number of young fledged. The results suggest that birds in a population do

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not experience immune trade-offs equally, either because of intrinsic differences among individuals, variation in overall resource availability at different times in the season or shifting resource-allocation priorities throughout the year.

27-4 Chapman, TL*; Bidwell, JR; East Tennessee State University; *chapmantl@goldmail.etsu.edu*

Field and behavioral analysis of microhabitat preference in two species of Plethodontid salamanders in the Southern Appalachian Mountains

This study examines the behavioral and physiological mechanisms that restrict the northern gray-cheeked salamander (*Plethodon montanus*) to high elevation habitats. Slimy salamanders (*Plethodon glutinosus*) serve as a potential competitor with *P. montanus* where their distributional boundaries overlap. Plot surveys at Rocky Fork (RFSP) and Roan Mountain (RMSP) State Parks, Tennessee, were used to identify elevation limits and habitat environmental conditions for each species. A novel system was constructed to test behavioral preference for temperature and relative humidity in a controlled setting for each species. Habitat environmental conditions were significantly different between the species at both study locations. In controlled trials, *P. montanus* behavioral preference was strongly correlated with average night temperature of collection day. We used a recently developed, non-invasive method of measuring cortisol (CORT) from dermal swabs to measure the CORT response during behavioral trials and when exposed to acute stress in the field. The next phase of this study will involve testing the CORT response of both species during a reciprocal transplant study at RMSP.

6-3 Chase, HT; University of Montana; *hilatzipora@gmail.com*

Decolonizing through interdisciplinarity: roots-based integration

In our pursuit to assuage issues of science and society, we often separate between outreach to underserved communities and issues of diversity inside academia. When minority students from these communities must assimilate to succeed in the dominant academic system, this harms the student, distances them from their community, increases distrust in academia, and invalidates the

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goals of diversity initiatives. Systemic reform like decolonizing academia is thus necessary to allow minorities to not only access careers but affect the system itself. In order to address such complex and integrated issues, however, we need a deeply integrative paradigm; Roots-Based Integration (RBI) seeks to meet this need. RBI uses a systems-based, relational approach to find and use existing connections rather than artificially "bridge" categorized disciplines. It provides hands-on training for the design, execution, and impact of integrative work, and forms a network of resources and support far beyond academia. In Spring 2020 I created a seminar called "Integrating Art and Science" as a pilot to apply RBI, with a cohort of 11 students from 9 disciplines. The course included both practical training in professional skills and theoretical training in relational thinking, non-Western approaches to knowledge, and other RBI principles. This enabled students to create interdisciplinary projects with extensive impacts that benefited their careers and design and pursue this work in a way that consciously and holistically aids in the decolonization and diversification of academia. A key factor in facilitating this was training students from a basis of respect: respect for different disciplinary approaches within the dominant academic system, and respect for different cultural approaches to learning and knowledge that promote exchange and collaboration, rather than the "bestowal" model often used in serving minority communities.

25-13 Chase, HT*; Tobalske, BW; University of Montana; *hilatzipora@gmail.com*

Trying to understand bird bone? You'll need reinforcements!

Though birds have long been admired by biologists and engineers alike for having "lightweight" bones with specialized "reinforcements," little work has been done to investigate the internal structure of wing bones. This internal matrix (trabecular bone) is a complex system of struts and plates found in epiphyses across vertebrates. While birds are not unique in having extensive trabecular matrices, they do appear unique in having larger, sparser structures that extend into the diaphysis. Long assumed to act like trusses, these "reinforcing structures" (RS) also seem to be a continuous part of the trabecular matrix, a highly complex

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structure more akin to a cellular solid. Recent studies model RS in the bird wing as either torsion-adapted ridges or bending-adapted struts. But observations of actual variation in RS across a broad phylogenetic sample of microCT scans shows far higher structural diversity than ever reported. We thus used a holistic, phylogenetic approach to investigate the mechanical role of these structures in the bird wing. Comparative, anatomical samples of bone containing RS were 3D printed and mechanically tested under both bending and torsion, paired with "hollow" versions (RS removed). Initial tests of a small flapping and large soaring species showed no obvious congruence with previous models- both performed better under bending than torsion, and neither showed significant differences in stiffness in hollow vs. intact trials. However, variation in stiffness was significantly lower in hollow than intact samples across both species and conditions. Ongoing work across species will better elucidate the complex mechanical role of wing-bone RS, and along with concurrent analyses on cortical-trabecular tradeoffs, these more holistic approaches will provide crucial insight into the functional morphology of bird flight.

BSP-11-8 Chaumel, J*; Schotte, M; Bizzarro, JJ; Zaslansky, P; Fratzl, P; Baum, D; Dean, MN; MPIKG, ZUSE, University of California, Charité Hospital; *julia.chaumel@mpikg.mpg.de*
Do the cells in stingray mineralized cartilage perform the roles of bone cells? Quantitative analysis of the lacuno-canalicular network in stingray tesserae
In most vertebrates the embryonic cartilaginous skeleton is replaced by bone during development. During this process, cartilage cells (chondrocytes) mineralize the matrix and mostly die, giving way to bone cells (osteocytes). In contrast, sharks and rays (elasmobranchs) have cartilaginous skeletons throughout life, where only the surface mineralizes, forming a layer of tiles (tesserae). Unlike other vertebrates, elasmobranch chondrocytes survive cartilage mineralization and are maintained alive within tesserae. However, the roles of the chondrocytes remain unknown. Analyzing synchrotron microCT scans of tesserae, we characterize variations in the morphologies and arrangements of stingray chondrocyte lacunae. We show that the cell density and cell volume do not differ between the unmineralized and mineralized tissue and,

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indicating they do not proliferate, hypertrophy and die as in other taxa. The cell density increases near pores passing through the tesseral layer, suggesting these may constitute a nutrients source. Tessera lacunae show distinct zonal variation in their shapes - being flatter further from the cartilage matrix and spherical in the center of tesserae-, and a strong orientation toward neighbouring tesserae, perhaps providing a fingerprint of the tesserae development, while indicating local variation in tissue strain and cell function. Lacunae are linked by small passages (canaliculi) in the matrix, connecting lacunae in series and creating a rich connectivity among cells and tesserae. These results indicate that these cells may interact and manage mineralization differently from chondrocytes in other vertebrates, perhaps performing analogues roles to osteocytes in bone

47-3 Cheatle Jarvela, AM*; Trelstad, CS; Pick, L; University of Maryland College Park; *ajarvela@umd.edu*

Genome editing in mosquitoes reveals evolutionary handover of regulatory gene function

Gene regulatory networks are the programs that translate genomic information into body plans and structures during development. Regulatory genes that compose such networks are often highly multifunctional and constrained, which results in evolutionary conservation. It is difficult to understand how a regulatory gene could be lost from the genome of one species when it is essential for viability in closely related species. The segmentation gene paired is a classic *Drosophila* pair-rule gene, required for formation of alternate body segments. *paired* is highly conserved; it is required for pair-rule patterning in distantly-diverged insects from flies to beetles. Surprisingly, *paired* was lost in mosquitos without morphological consequence on body patterning. Here, we demonstrate that a *paired* family member, *gooseberry*, has acquired *paired*-like expression in *Anopheles stephensi*, the Asian malaria mosquito. Using CRISPR-Cas9, we generated a targeted knock-out of *Anopheles-gooseberry* and found that mutants display pair-rule phenotypes similar to those seen for *Drosophila-paired*. Further, this loss-of-function mutation in *gooseberry* resulted in the same alteration of downstream target gene expression observed in *Drosophila* and beetle *paired* mutants. Thus, *paired* was

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functionally replaced by the related gene, *gooseberry*, in mosquito lineages. Our findings document a rare example of a functional replacement of an essential regulatory gene and provide a mechanistic explanation of how the loss of regulatory genes can occur during evolution.

105-11 Chen, W*; Zhu, J; Stankovic, J; Lauder, GV; Bart-Smith, H; University of Virginia, Harvard University; *wc5qd@virginia.edu*
Tuna robotics: using machine learning and inertial measurement sensors for sensory feedback during swimming
Sensory feedback information is essential for fish to explore and inhabit various habitats or survive predator-prey encounters. Inspired by fish lateral line sensory systems, numerous flow sensors have been successfully developed based on MEMS technology which has the potential for applications on autonomous underwater vehicles. However, many challenges, such as robustness against extreme underwater conditions, installation, and signal readout, need to be overcome to realize this promise. To overcome the challenges, we present Vibot, the first non-invasive inertial measurement unit (IMU) method to understand and recognize fluid interactions with the robotic fish. Vibot works by using a commercial off-the-shelf IMU to study interactions between a tuna-inspired robotic platform, the Tunabot, and a variety of flow conditions including laminar flow, a Kármán vortex street, and wall effects. We propose a vibration model of fluid Interactions and utilize an Artificial Neural Network (ANN) to analyze and recognize different water flow conditions. Experiments are carried out in a water channel with the Tunabot platform. Results will be presented and compared with previous results using MEMS flow sensors.

73-4 Chen, Y; DeJong, JT; Jaeger, RA; Martinez, A*; University of California Davis, California Department of Water Resources; *amart@ucdavis.edu*
Scaling of burrowing resistances with sediment depth: a geomechanical perspective
Burrowing by animals such as marine worms, earthworms, and clams requires overcoming sediment resistances. Two of the resistances that influence an animal's burrowing ability are the soil

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penetration resistance experienced at the burrow tip and the radial expansion pressure on the burrow walls. The magnitude of these depends on the sediment properties and depth. We perform numerical simulations to investigate the dependency of the penetration and radial expansion pressures on depth in soil of varying density. We use a 'tip and anchor' template, where the tip is advanced longitudinally and the anchor is expanded radially. We perform simulations using a cavity expansion (CE) analytical solution and a discrete element modeling (DEM) code calibrated to model the behavior of a sandy soils. The simulation results show that the relationship between penetration resistance, anchor radial pressure, and depth can be described using power-law relationships. The radial pressure increases at a greater rate as the depth is increased (exponent of 0.74 from CE and of 0.82 from DEM) than the penetration resistance (exponent of 0.69 from CE and of 0.69 from DEM) for sediments with high density. However, as the density is decreased, the rate of increase in both pressures becomes comparable (exponent of 0.79 for both from CE in low-density sediment). These results suggest that as the 'tip and anchor' burrowing strategy becomes more advantageous at greater depths. These results support previously-published observations indicating that marine worms that burrow at greater depth use variations of the 'tip and anchor' template such as peristalsis and the so-called 'dual-anchor' strategy, while animals that burrow at shallower depths use different strategies.

103-9 Cheu, AY*; Bergmann, PJ; Clark University; *acheu@clarku.edu*
Choose your own adventure: Performance and kinematics of multiple climbing and swimming strategies in lizards
Based on the physical composition of their environment, animals are often required to perform various modes of locomotion. However, within each mode there may be several different strategies that an animal can employ. It is unknown whether these strategies differ in the level of performance and how such potential differences are mediated by body and limb kinematics. Such performance differences may have behavioral and ecological implications where, for example, if one strategy had a higher velocity and the other has higher acceleration an animal may use the former to pursue prey and the latter to escape predators. In basilisk lizards (*Basiliscus*

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vittatus), climbing can be achieved with either the limbs being used synchronously, akin to hopping up a vertical surface, or asynchronously, where the left and right hind limbs are out of phase. In swimming locomotion, these lizards will often perform swimming by axial undulation with their limbs folded against their body, but they can also adopt paraxial swimming, using their hindlimbs to kick. Here we address the question: How do the different strategies within each mode of locomotion differ in their performance and kinematics? This study aims to address (1) if the maximum and average velocities and accelerations and axial kinematic variables differ between synchronous versus asynchronous gaits in climbing and between paraxial and axial swimming strategies and (2) if higher performance in one strategy correlates with increased frequency of use of that strategy over the other.

58-4 Chiari, Y*; Moreno, N; Roy, R; Kostanecki, A; Brockman, S; Holl, C; Solhaug, EM; Minami, A; Hampton, M; Bee, M; Hegeman, A; Carter, C; George Mason University, University of Minnesota, University of Minnesota; *ychiari@gmu.edu*

Preference for colored nectar in Phelsuma laticauda

Many flowering plants rely on pollinators to spread their pollen. Although insects are the most common pollinators of flowering plants, other animals, including bats and lizards, also perform this role. Depending on their main pollinators, plants may evolve different floral color to attract the pollinators and nectar and pollen to reward them. Among the flowering plants that have nectar, only a few of them have colored nectar, which may also work to attract pollinators. In Mauritius, the flowering plant Nesocodon mauritianus has blood-red nectar - which stands out as a color contrast from its flower - and is pollinated by day geckos belonging to the genus Phelsuma. These flowers are found on vertical cliffs in areas within the distribution of at least one species of Phelsuma day geckos. Previous studies have shown that some Phelsuma geckos prefer red-colored nectar over clear nectar with the same composition. Here we present our results on visitation and feeding of colored vs. non-colored nectar for another species of Phelsuma, P. laticauda - which does not occur in the same environment as N. mauritianus. Our results indicate a clear preference in terms of visitation and feeding for the colored

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nectar suggesting that preference for red-colored nectar may be widespread in the genus Phelsuma.

36-10 Childers, JL*; Bowie, RCK; Museum of Vertebrate Zoology, UC Berkeley; *jchilders@berkeley.edu*

Evolution of elaborate nest design in the Old World weavers (Ploceidae)

Nest structures are widespread across animals and yet are one of the most understudied components of avian life history. Some of the most remarkable examples of elaborate nest design are within the Weaverbirds (Ploceidae), an Old World family of Passerine birds containing 117 species in 17 genera, making them an ideal model system for studying evolutionary patterns of biodiversity. While it is known that each species constructs a uniquely designed nest, the evolutionary factors that influence design are unknown. Previous work on Weaverbird nests has focused on qualitative descriptions of nest design and shape within the subfamily Ploceinae, and no study to date has attempted to include fine-scaled nest character data using continuous and meristic measures of nest design within a phylogenetic framework. For this study we collected data for 30 morphological variables related to nest size, shape and material composition from 576 nest specimens housed in several natural history collections in North America and Europe (NHM, WFVZ, ZMB). Our sampling includes representatives from 82 species in 13 genera, representing over 70% of the taxonomic diversity across the Ploceidae. Comparative statistics have resulted in the identification of 9 highly informative nest character traits that vary significantly between species including overall nest volume, egg chamber length, entrance diameter size, and entrance tube length. Currently our research involves taking these initial results and placing them within a phylogenetic context by combining our nest character data with existing DNA sequence data for the Ploceidae to perform ancestral state reconstruction and trait-dependent diversification analyses.

S4-16 Childress, MJ*; Tallapragada, M; Prosser, KL; Clemson University, Temple University, Educational Entertainment; *mchildr@clemson.edu*

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Something Very Fishy: An ocean literacy STEAM exhibit impacts how children, teachers, and university students think about science
Informed by the theory of change for public engagement and decades of research in communication and education, we present a quantitative assessment of a marine science themed STEAM exhibit focused on ocean conservation and climate change. Our target groups included elementary school students and their teachers who attended a musical theatrical production and companion science exhibit manned by university student docents. The school children were provided an SVF student workbook in advance of attending the exhibit and were asked to complete assessments pre and post-exhibit including: (1) a drawing of what it looks like under the sea, (2) choosing their three favorite careers survey, and (3) gauging their feelings and interests in the program survey. For teachers and docents, we used a post exhibit survey to assess their attitudes, knowledge, norms, careers, and intentions toward science, climate change, and ocean literacy. After attending the exhibit children demonstrated an increased awareness of the role that humans have on our oceans and an increased interest in STEM related career options. Elementary teachers showed a positive attitude toward teaching marine conservation and climate change and willingness to participate in further training in these subjects. University student docents that participated in the exhibit as instructors demonstrated an efficacy for teaching marine science and an identity toward science communication as a career. These results have implications for researchers exploring the impact from informal experiences on attitudes, knowledge, norms, intentions, and careers of students, and for practitioners and teachers exploring ways to use art to teach about the environment.

31-5 Chinn, SM*; Kilgo, JC; Vukovich, M; Beasley, JC; University of Georgia, USDA Forest Service Southern Research Station, New Ellenton, SC ; *sarahchinn@uga.edu*
Intrinsic effects on neonate survival of an invasive large mammal
An understanding of factors influencing survival of neonate wild species is important for successful management, particularly for determining drivers of population dynamics. Wild pigs (*Sus scrofa*) are non-native in the U.S., where populations are rapidly increasing in part due to high reproductive capacity. Survival of

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adults is generally high and less variable than younger age classes. However, survival of piglets, and particularly neonates, is largely unknown due to difficulty in capturing and tracking individuals. Our objectives were to locate neonates at the natal nest and quantify survival to six weeks in relation to individual biological attributes and stochastic environmental variables. During 2017-2020, we captured 50 neonates from 15 litters and documented 26 mortalities (52%) over six weeks. Survival was positively influenced by wild pelage coloration, likely as a form of camouflage from predators, as well as sow condition where sows may have higher lactation capacity and flexibility to decrease foraging immediately after birth to remain attentive at the nest. Larger sows may also be better able to defend neonates from predators. Using average temperature of the natal nest area (within 25m), average nest area luminosity and percent canopy cover we created a second set of candidate extrinsic models to assess survival to 10 days. None of these parameters showed a significant influence on survival as the null model was included in the top-ranked models. These are the first data for neonate wild pig survival and will inform population models for the development of management strategies to reduce negative impacts of this destructive invasive species on native ecosystems.

47-2 Chipman, AD; The Hebrew University; *ariel.chipman@huji.ac.il*
The developmental basis of insect tagmatization
The segmented body plan is one of the hallmarks of arthropod structure. Morphological segments are formed during embryogenesis, through a complex procedure involving the activation of a series of gene regulatory networks. The segments of the arthropod body are organized into functional units known as tagmata, and these tagmata are different among the arthropod classes (e.g. head, thorax and abdomen in insects; prosoma and opisthosoma in arachnids). Recent work has shown that the process of segmentation varies for different tagmata within the same embryo, and that these differences appear to be consistent across arthropods. For example, in many insects, gnathal and thoracic segments are generated simultaneously during an early developmental stage, whereas abdominal segments are generated sequentially from a posterior growth zone during the germband stage. I will focus on work

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on *Oncopeltus fasciatus*, but also compare to work carried out on additional species. Looking back at the arthropod fossil record with this embryological insight, allows us to understand the functional changes underlying major transitions in the evolution of the arthropod body plan.

65-9 Chmura, HE*; Burrell, G; Buck, CL; Barnes, BM; Williams, CT; University of Alaska Fairbanks, Northern Arizona University; *hchmura@alaska.edu*
Soil freeze date and onset of sub-zero heterothermy in hibernating arctic ground squirrels track climate change in Arctic Alaska
Hibernation evolved as a means of energy conservation during periods of resource scarcity. By depressing metabolic rate and body temperature, animals reduce energy demand and persist on endogenous and stored reserves. Arctic ground squirrels are extreme hibernators, exhibiting sub-zero body temperatures while hibernating in burrows that may be as cold as -20C. To survive such low ambient temperatures, arctic ground squirrels exhibit thermogenic torpor, which means they defend low torpid body temperature set points through the expenditure of fat reserves. Two reliable signals of climate change in the Arctic are soil warming and changes in the timing of seasonal soil freeze-thaw cycles. These changes have the potential to affect arctic ground squirrels, and other hibernators, by warming burrow temperatures and changing the duration of the sub-zero heterothermic season. Here we examine long-term records of soil temperature and the phenology of hibernation in free-living arctic ground squirrels collected at two field sites on the North Slope of Alaska for signatures of rapid climatic warming. We show that over the last twenty-five years, the duration of seasonally frozen soil has shortened. At the same time, the onset of sub-zero heterothermy is occurring later in hibernating ground squirrels. We discuss the implications of these results for hibernating animals and hibernation as a life history strategy given continued climate change.

9-3 Chow, A*; Lord, N; Louisiana State University AgCenter, Department of Entomology, Baton Rouge, LA; *ablechow29@gmail.com*

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Jewels of iridescence: Mechanisms of structural color and its significance in insect systematics

Taxonomy defines the basic categories on which all biological research operates. In Jewel Beetles (Coleoptera: Buprestidae), the 8th most speciose Coleopteran family with >15,000 species, color is often utilized to distinguish between morphologically similar species. The taxonomically difficult genus Chrysochroa is assembled of several morphologically conserved species-complexes that exhibit a diversity coloration, and differential interpretations of perceived color have furthered taxonomic instability. Colors in the members of *Chrysochroa* are produced through organized, alternating layers of melanin and chitin in the epicuticle, forming Bragg stacks which selectively reflect specific wavelengths of light and change with the angle of light and the observer. In this research, we investigate color as an extended phenotype in the form of spectral reflectance measured through spectrophotometry, and as ultrastructural morphology analyzed through transmission electron microscopy (TEM) and scanning electron microscopy (SEM). The resulting color data was combined with morphological and biogeographical analysis to produce a revision of the subgenus *Chrooxantha* (Buprestidae: *Chrysochroa*). Superficially similar taxa previously classified as the same species were revealed to possess distinctly different spectral reflectance patterns produced by divergent epicuticle ultrastructure. Dissection further revealed species level differences in internal morphology, and distributional boundaries indicative of allopatric speciation were discovered through biogeographical analysis. The ability to evaluate color objectively at multiple levels has opened up new suites of highly informative characters previously unavailable to taxonomists enabling further research in evolution and systematics.

80-1 Christensen, BA*; Schwaner, MJ; Lin, DC; McGowan, CP; University of Idaho, Moscow , University of Idaho, Moscow, Washington State University, Pullman ; *chri4094@vandals.uidaho.edu*

Elastic energy storage across speeds during steady state hopping of desert kangaroo rats (Dipodomys deserti)

While effective "biological springs" are present across species, large bipedal hoppers (i.e., kangaroos and wallabies) offer model

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examples of elastic energy storage and return mechanisms. For example, for these species, oxygen consumption during steady-state hopping does not increase linearly with speed as expected, but rather stabilizes as speed increases. Despite body design similarities, smaller bipedal hoppers, such as desert kangaroo rats, do not exhibit this energetic benefit. They are also thought to not benefit from analogous elastic energy storage due to comparatively thick tendons. However, recent material properties research reports a lower elastic modulus for the species' ankle extensor tendons than originally assumed. These new elastic moduli values prompted our inquiry into how an increase in speed influences elastic energy recovery by kangaroo rats. For direct *in-vivo* measurements, a buckle force transducer was surgically attached to the ankle extensor tendons as animals (*N* = 3) hopped across a range of speeds (1.3 - 1.9 m/s). Increased speed resulted in increased tendon stress, rising from 2.69 MPa to 3.49 MPa, and increased energy storage, ranging from 0.88 mJ to 1.5 mJ. Based on estimated mechanical power requirements, results indicate energetic return is optimized at specific speeds, with percent energy savings increasing from 3.85% at 1.3 m/s to 5.19% at 1.7 m/s, but then falling to 4.38% at 1.9 m/s. Future analysis will include *in-vivo* strain assessments of individual ankle extensor muscles to better understand the patterns underlying labor division between muscle work production and elastic energy storage during hopping.

BSP-8-9 Chugh, S*; Maruska , K; Louisiana State University,Baton Rouge,LA; *schugh1@lsu.edu*

Role of nesfatin-1 in energetic state and maternal mouthbrooding in a cichlid

Role of nesfatin-1 in energetic state and maternal mouthbrooding in a cichlid .Chugh, S and Maruska, K Schugh1@lsu.edu Louisiana State University, Baton Rouge, LA. Feeding and energetics are fundamental processes in all species that must be balanced with reproductive investment.The regulation of reproduction and feeding is complex, with many hormones that act via central and peripheral mechanisms.While many regulatory molecules are well studied, a relatively new candidate peptide, nesfatin-1 (encoded by the *nucb2* gene), has emerged as a key player involved in both feeding and reproduction across vertebrates. Studies in diverse

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vertebrate taxa show that it reduces appetite via central and peripheral regulation and has effects on reproduction. How nesfatin-1 might help regulate trade-offs between feeding and reproduction, however, is unexplored. The female cichlid fish *Astatotilapia burtoni* is an ideal system to examine the role of nesfatin-1 in feeding and reproduction because it cycles between a gravid feeding state while preparing to mate, and a forced starvation state while carrying the developing young in their mouths for ~2 weeks. To test whether female energetic state associated with mouthbrooding was linked with changes in the central nesfatin-1 system, we compared the number and size of *nucb2*-expressing cells in the brain of mouthbrooding, starved and fed females using *in-situ hybridization*. Using qPCR we measured *nucb2* mRNA levels, also testing for similar differences in peripheral tissues (stomach, liver and intestine). Examining central and peripheral *nucb2* levels in the same females helps explain the role of nesfatin-1 in allocating energy during the female reproductive cycle. Our study will lead to a better understanding of the evolution of nesfatin-1 regulatory pathways, which also has biomedical implications for treatment of obesity and diabetes.

S2-9 Churches, N; Chancellor, J; Chang, P; Nuzhdin , S*; Univ. Southern California, Seedoffshore, LLC; *snuzhdin@usc.edu*

Pacific oysters (Crassostrea gigas) dramatically recalibrate the model for the upper limit of the eukaryotic mutation rate

The study of bivalves is currently enjoying a significant increase in both private and scientific interest, and duly so. Bivalves have historically been implemented in studies investigating strange evolutionary phenomenon (e.g. Sweepstakes Reproductive Success), rare genetic transmission mechanisms (e.g. doubly-uniparental mitochondrial inheritance), sentinel species for ocean acidification response, and more recently as a sustainable food source for the future and domestication target. The generational mutation rate in the emerging bivalve model organism the Pacific oyster, Crassostrea gigas, had previously been hypothesized to be among the highest yet estimated in eukaryotes, however empirical proof was absent. The study presented for consideration here uses whole genome sequencing data from trios (mother, father, and a set of offspring) to directly and empirically estimate per nucleotide

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mutation rate for the first time in mollusks, using the Pacific oyster. We found that the Pacific oyster has a mutation rate that is 2-3 orders of magnitude larger than any yet reported among eukaryotes (~10-5 per base per generation). This finding shifts the upper limit of hypothesized mutation rate for eukaryotes, similarly, 2-3 orders of magnitude, and indicates that perhaps organisms undergoing type III/r-selected survivorship within chaotic oceanic environments may be under selective pressure to decrease or eliminate basic molecular functions, including DNA replication fidelity. Our findings implicate the use of the Pacific oyster an ideal system for studying novel DNA replication machinery, and will have a significant impact for evolutionary theory studies and selective breeding programs alike.

72-1 Cieri, RL*; Dick, TJM; Clemente, CJ; University of the Sunshine Coast, Sippy Downs, Queensland, Australia; *bob.cieri@gmail.com*

Ground reaction forces in monitor lizards (Varanidae) and the scaling of locomotion in sprawling tetrapods

Geometric scaling predicts a major constraint for legged, terrestrial locomotion. Locomotor support requirements scale isometrically with body mass (α M^1), while force generation capacity should scale α $M^{2/3}$ as it depends on cross-sectional area. Mammals compensate with more erect postures at larger sizes, but it remains unknown how sprawling tetrapods deal with this constraint. Varanid lizards are an ideal group to address this question because they cover an enormous body size range while maintaining similar posture and body proportions. This study reports the scaling of ground reaction forces and duty factor from varanid lizards ranging from 7-37,000 g. Impulses (α $M^{0.96-1.34}$) and peak forces (α $M^{0.72-0.98}$) scaled higher than expected. Duty factor scaled α $M^{0.04}$ and was higher in the hindlimb than in the forelimb. The proportion of vertical impulse to total impulse increased with body size, and impulses decreased while peak forces increased with speed. Muscle parameters (fascicle length, muscle mass, and physiological cross-sectional area) were also found to scale with positive allometry in varanids, suggesting that varanid lizards respond to predicted biomechanical demands of increased body size with both anatomical and kinematic adjustments. Peak forces scale (> $M^{2/3}$), suggesting

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that muscle and skeletal strength increases with positive allometry, but (< M^1), suggesting that larger varanids also increase duty factor to spread body support over a longer period. These results provide insight into the biomechanics of extinct, sprawling megafauna.

55-2 Clardy, TR*; Deary, AL; Natural History Museum of Los Angeles County, Alaska Fisheries Science Center, NOAA; *tclardy@nhm.org*

Ontogeny of the feeding apparatus of the white croaker, Genyonemus lineatus (Sciaenidae)

The anatomy of the feeding apparatus of fishes, including the oral and pharyngeal jaws, is closely linked with ecology. Elements of the jaws can undergo drastic changes during development as species transition from larval diets to specialized adult diets. The timing of feeding apparatus specialization can be crucial for species that differentiate into specialized foraging habitats. The family Sciaenidae is a species-rich group of nearshore fishes with varied, specialized diets as adults and can be classified into three broad foraging guilds: benthic, generalist, and pelagic. Ontogenetic trajectories of jaw development have been evaluated for sciaenids in the Northwestern Atlantic but have not been evaluated for sciaenids in the Northeastern Pacific. Here, we examine jaw development of the White Croaker, *Genyonemus lineatus*, a generalist sciaenid that ranges from Baja, Mexico to Northern California, USA, and is exploited recreationally. A developmental series of *G. lineatus*, ranging from 4.1 to 43.2 mm TL, was cleared and stained. Anatomical features of the oral and pharyngeal jaws and gill arches were measured to assess development of the feeding apparatus. The observed patterns for *G. lineatus* then were compared against sciaenids from the Northwestern Atlantic from benthic, generalist, and pelagic guilds to test whether Northeastern Pacific sciaenids share similar developmental trajectories. Ecomorphological studies such as this one are robust and applicable to fisheries management. Once links are established between an individual species' anatomy and stage-specific ecology, essential fish habitat requirements can be forecast for less studied, but exploited, fishes throughout their life history.

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S3-4 Clark, CJ; University of California, Riverside; *cclark@ucr.edu*
Seven ways that wings produce sound in flight
Acoustic communication sounds evolve when receivers begin to attend to sounds that were previously an incidental byproduct of another process. Here, we review the physical acoustic mechanisms by which wings intrinsically produce sound. The first mechanism intrinsic to all flapping wings is the aerodynamic reaction to lift and drag, in the form of low frequency, tonal sound. This mechanism is responsible for hummingbird humming and the tonal wing whine of mosquitoes and other insects. The second mechanism is production and scattering of turbulence by the wing, which usually generates atonal sound. The third mechanism is friction: elements within a wing (i.e., feathers) slide against each other, generating localized vibrations that are transmitted to the air as sound that is broadband (atonal). This effect appears to be widespread in bird flight, and possibly in some large insects such as grasshoppers. The fourth mechanism is collisions (percussion), such as when a wing collides with another object, and generates impulsive, atonal sound. A few birds and possibly one bat produce communication sound in this way. The fifth mechanism is a stiff element that can snap back and forth between two stable states (a tymbal). Insect cuticle is predisposed to do this, and this usually atonal mechanism has evolved several times in insects such as grasshoppers and butterflies. The sixth mechanism is flutter: an element activated by airflow oscillates at a natural frequency. Feathers are predisposed to flutter and this mechanism is widespread in birds. We finish with examples of sounds for which the physical acoustic mechanism is not yet understood, including the drumming sound made by Ruffed Grouse, and clapping (such as of dove wings). These sounds might be the product of a seventh mechanism, trapped air escaping from a confined space, similar to the mechanism produced by clapping human hands.

97-11 Clark, AE*; Meredith, TL; Porter, ME; Florida Atlantic University, Florida Atlantic University ; *clarka2014@fau.edu*
Using diceCT to quantify in situ olfactory rosette morphology among elasmobranchs
Although the general morphology of the olfactory system in elasmobranchs (sharks, rays, and skates) is structurally similar

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among species, there is variation in the shape and structure of the paired olfactory rosettes. Previous studies on the morphology of olfactory rosettes, which are composed of soft tissue that is situated within a rigid cartilaginous capsule in the cranium, involved the dissection of the organs from the cranium. A limitation of this method is that the organs do not retain their natural positioning and shape because they lose the structure that is provided by the capsule. The goal of this study was to provide quantification of *in situ* rosette morphology through diffusible iodine-based contrast-enhanced computed tomography (diceCT), which uses Lugol's iodine as a contrast agent. Fresh whole-head specimens from order Carcharhiniformes were fixed in 10% buffered formalin, then placed into 5% Lugol's iodine solution for several days. Scans were performed using a Bruker SkyScan 1173 and 3D reconstructions were made using Bruker NRecon and CTVox software. Rosette length and width, fineness ratio (a 2D representation of shape), and capsule volume were measured using CTAn software. Rosettes were clearly visible after being stained for five days in Lugol's solution. Using Welch's t-test, we found that fineness ratios measured on the dissected organs were not significantly different than those obtained *in situ*. Volume measurements taken *in situ* were also not significantly different than the values from dissected organs. The data collected from this study can be used to create 3D models to examine the effects of capsule and rosette shape on water flow throughout the elasmobranch olfactory system.

5-9 Clark, DL*; Hauber, ME; Anderson, PSL; University of Illinois at Urbana-Champaign; *dlclark2021@gmail.com*

Nest substrate and tool shape significantly affect mechanics and energy requirements of avian eggshell puncture

Some host species of avian obligate brood parasites reject the parasitic eggs whereas others accept them, even though they recognize them as foreign. One hypothesis to explain this seemingly maladaptive behavior is that acceptors are unable to pierce and remove the parasitic eggshell. Previous studies reporting on the force and energy required to break brood parasites' eggshells were typically static tests performed against hard substrate surfaces. Here, we considered host nest as a substrate to simulate this potentially critical aspect of the natural context for egg puncture

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to occur while testing the energy required to break avian eggshells. Specifically, as a proof of concept, we punctured domestic chicken eggs under a series of conditions: varying tool shape (sharp vs. blunt), tool dynamics (static vs. dynamic), and the presence of natural bird nests (of three host species). The results show a complex set of statistically significant interactions between tool shapes, puncture dynamics, and nest substrates. Specifically, the energy required to break eggs was greater for the static tests than for the dynamic tests, but only when using a nest substrate and a blunt tool. In turn, in the static tests, the addition of a nest significantly increased energy requirements for both tool types, whereas during dynamic tests, the increase in energy associated with the nest presence was significant only when using the sharp tool. Characterizing the process of eggshell puncture will help in understanding whether and how hosts of brood parasites evolve to reject parasitic eggs.

105-7 Clark, AD*; Tytell, ED; Tufts University; *andrew.clark3@tufts.edu*

Fin kinematics during acceleration and turning in fishes: using a novel method to regularly produce irregular behaviors

In a natural setting, many fish species will regularly turn, accelerate, and perform other unsteady behaviors, while occasionally swimming steadily in one direction. Even though such irregular maneuvers make up the majority of underwater life, we know little about them because it is difficult to repeatedly reproduce such behaviors in a laboratory setting. Here we ask how specific fins move to contribute to turning in fishes using a novel device to repeatedly elicit specific unsteady maneuvers. We have developed a programmable "car" with an attached flow-through chamber mounted within the working section of a flow tank. The car can move backwards and forwards in a controlled manner, which causes the fish to turn around, back up, or slow down. By manipulating the speed of the car as well as the speed of the flow in the flow tank, we are able to consistently produce many different unsteady behaviors, allowing an in-depth look into behaviors that are otherwise not very repeatable. Our method is robust and elicits repeated actions that are consistent among trials within one individual, between trials of different

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individuals of the same species, and even between trials of different species. We quantify fin movements including tail flaring, pectoral fin movement, and movement of the dorsal and anal fins in both bluegill sunfish and largemouth bass, using a computer vision technique called DeepLabCut. Our work is one step along the path to better understanding unsteady maneuvers in fishes and will improve our knowledge regarding the mechanics, morphology, and control systems behind behaviors that have previously proved difficult to observe in a consistent and controlled manner.

108-10 Claunch, NM*; Goodman, CM; Reed, RN; Romagosa, CM; Taylor, EN; University of Florida, University of South Florida, United States Geological Survey, Fort Collins, CO, California Polytechnic State University, San Luis Obispo; *nmclaunc@ncsu.edu*

Invaders sourced from islands: thermal matching, potential or plasticity?

Invasive species originating from islands are released from native-range constraints such as thermal or geographic barriers. Climate matching may thus underestimate likely invasion sites for island natives. Physiological limits determine survival at thermal extremes, but rapid physiological adaptation may occur in species introduced to new environments. *Leiocephalus carinatus* is a lizard native to the Bahamas and Cuba and has established multiple disjunct populations in Florida, including populations north of its native range. Competing hypotheses may explain the successful invasive distribution of *L. carinatus*: 1) Distribution in both native and invaded ranges is constrained by the thermal conditions of the native range (Thermal Matching); 2) Distribution in the native range is constrained by geographic barriers rather than thermal conditions; lizards can tolerate environments with thermal extremes not observed in the native range (Thermal Potential); 3) Introduction to environments with differing thermal extremes leads to physiological adaptation/acclimatization to one or both extremes (Thermal Plasticity). We rejected the Thermal Matching hypothesis by comparing ecological niche models developed from the native-only range to models including invasive populations. We investigated the Thermal Potential and Thermal Plasticity hypotheses by comparing critical thermal limits of 35 L. carinatus from each of two established Florida populations, one matching latitudes in the

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native range, and another 160 km north of the native range. Critical thermal minima in the northern population were lower than in the south, supporting the Thermal Plasticity hypothesis for thermal minima.

24-4 Clemente, CJ*; Schultz, JS; Beck, HK; Haagensen, T; Proost, T; University of the Sunshine Coast, Hochschule Bremen; *cclement@usc.edu.au*

Using a biologically mimicking climbing robot to explore the performance landscape of climbing in lizards

The life and death of an organism often depends on its ability to perform well at some ecologically relevant task. Yet despite this significance we have little idea how well species are optimised for competing locomotor tasks. Most scientists generally accept that the ability for natural systems to become optimised for a specific task is limited by structural, historic or functional constraints. Climbing lizards provide a good example of constraint where climbing ability requires the optimization of conflicting tasks such as speed, stability, or efficiency. Here we reconstruct multiple performance landscapes of climbing locomotion using a 10-DOF robot based upon the lizard bauplan, including an actuated spine, shoulders, and feet, the latter which interlock with the surface via claws. This design allows us to independently vary speed, foot angles, and range of motion, while simultaneously collecting data on climbed distance, stability and efficiency. We first demonstrate a trade-off between speed and stability with high speeds resulting in decreased stability and low speeds an increased cost of transport. By varying foot orientation of fore and hindfeet independently, we found geckos converge on a narrow optimum for both speed and stability, but avoid a secondary wider optimum highlighting a possible constraint. Modifying the spine and limb range of movement revealed a gradient in performance. Evolutionary modifications in movement among extant species appear to follow this gradient towards areas which promote speed and efficiency. This approach can give us a better understanding about locomotor optimization, and provide inspiration for industrial and search-and-rescue robots.

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16-4 Clunis, P*; Ryder, TB; Dakin, R; Carleton University, Bird Conservancy of the Rockies; *paisleyclunis@cmail.carleton.ca*

Reciprocity is a pathway to social network stability

Social reciprocity can promote the evolution of cooperation and long-term social bonds. However, the causes and consequences of partner reciprocation within a social network are not well understood. We studied social reciprocity in the wire-tailed manakin (*Pipra filicauda*), a bird species in which the males establish partnerships and perform coordinated displays on lek territories. When two territory holders interact, the visiting bird forgoes potential mating opportunities by leaving his own territory. These directed social network interactions present an opportunity to test whether social reciprocation occurs, and whether it is associated with partnership strength and stability in the broader social network. We used automated telemetry to track social behavior over three years in a large population, observing far more reciprocated partnerships than expected in a null model of territory visitation. The reciprocated partnerships were stronger (i.e., partners interacted more frequently) than non-reciprocated partnerships independent of spatial proximity. Using an individual-level analysis, we show that a male's donation to a given partner was also positively correlated with the number of social interactions he received from that partner, controlling for other factors. Finally, we show that reciprocated partnerships retained greater strength than one-directional partnerships a year later. These results suggest that reciprocity can act as a pathway to stability in cooperative social partnerships, and by extension, the broader social network.

35-7 Cochrane, PV*; Jonz, MG; Wright, PA; University of Guelph, ON, Canada , University of Ottawa, ON, Canada; *cochranp@uoguelph.ca*

Development of the O2 sensing system in an amphibious fish

Proper development of the O_2 sensing system is essential for survival. However, the development of the O_2 sensing system in animals can be altered by exposure to high/low O_2 levels during early life. We characterized the development of the O_2 sensing system in the mangrove rivulus (*Kryptolebias marmoratus*), an amphibious fish that transitions between hypoxic aquatic environments and O_2-rich terrestrial environments. We found that

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the development of serotonergic O_2-sensitive chemoreceptors (neuroepithelial cells; NECs) on the gills of *K. marmoratus* is accelerated relative to the only other species of fish studied to date, zebrafish, and that cutaneous NECs are retained from the larval stage to adulthood. We also found that the hyperventilatory response to acute hypoxia is present in embryonic *K. marmoratus*, indicating that functional O_2-sensing pathways are formed during embryonic development. We then exposed embryos to aquatic normoxia, aquatic hyperoxia, aquatic hypoxia, or terrestrial conditions for the first 30 days of development and tested the hypothesis that environmental O_2 availability during embryonic development modulates the development of the O_2 sensing system in amphibious fishes. Surprisingly, we found that O_2 availability during embryonic development did not influence the development or morphology of NECs on the gills and skin of *K. marmoratus*. Collectively, our results demonstrate that, unlike zebrafish, the development of the O_2 sensing system is insensitive to environmental O_2 levels during the embryonic stage, suggesting that life history differences may underlie interspecies variation in plasticity.

68-5 Coffin, JL*; Onnen, J; Tobler, M; Kansas State University; *jlcoffin3@gmail.com*

Maternal effects throughout development in fishes inhabiting extreme environments

Extreme environments characterized by harsh physiochemical stressors provide ideal natural laboratories for testing *a priori* hypotheses about the mechanisms behind adaptation and ecological speciation. Hydrogen sulfide (H_2S) is a potent respiratory toxicant that inhibits aerobic ATP production. H_2S-rich springs throughout Latin America have been independently colonized by fishes within the family Poeciliidae, mediated largely by convergent adaptation to physiochemical stress from H_2S exposure. Mounting evidence suggests that environmental conditions experienced by the mother prior to birth can shape the phenotype of offspring through maternal effects. Maternal effects can lead to adaptive change if the mother's environment leads to a shift in offspring phenotype that improves the match between offspring phenotype and its own environment, but these effects can also be

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neutral or maladaptive if this match is not affected or worsened. In this study, we quantified the impact of maternal food access during gestation and maternal population of origin (sulfidic or non-sulfidic) on numerous life history (size at birth, growth rate, and age at sexual maturity) and behavioral phenotypes (boldness, predator avoidance, and feeding efficiency) related to competitive ability throughout development in Atlantic mollies (*Poecilia mexicana*). We predicted that, for each phenotype tested, neonates from non-sulfidic mothers would perform significantly better than neonates from sulfidic mothers, and that neonates from well-fed mothers would outperform those from poorly fed mothers, representing a tradeoff between tolerance to abiotic stress and competitive ability in the sulfidic population. This work represents a novel approach to investigating the impacts of maternal effects on adaptation to environmental stress.

41-3 Cohen, RE*; Land, AM; Martensen, BF; Sharlin, DS; Smith, BA; Minnesota State University, Mankato; *rachel.cohen@mnsu.edu*
Transforming the undergraduate curriculum - engaging first year students in authentic research experiences
The Department of Biological Sciences at Minnesota State University, Mankato has recently implemented a first-year undergraduate research experience (called the Research Immersive Scholastic Experience in Biology program; RISEbio) designed to improve student success and engagement in biology. In this program, first year students exchange introductory biology labs for the RISEbio curriculum, where they learn basic laboratory, analytical and scientific reasoning skills before beginning authentic mentored research projects in their second and third semesters. Students in one of three research tracks examine the neural control of reproductive behavior by examining gene expression in the brain of the seasonally breeding green anole lizard (*Anolis carolinensis*). Working in groups, students gain experience with bioinformatics by examining preliminary RNA-seq data and selecting a gene of interest. Then, students design and test primers to amplify their gene of interest, followed by isolating RNA from the hypothalamus of breeding and non-breeding lizard brains. Lastly, students utilize their isolated RNA samples and validated primers in quantitative RT-PCR studies to determine if their gene of interest

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is differentially expressed in the anole brain. Preliminary work has identified melatonin receptor 1A (MTNR1A) as more highly expressed in the breeding compared to non-breeding anole hypothalamus, while corticotropin releasing hormone binding protein (CRHBP) expression does not differ seasonally. Together with other aspects of the RISEbio program, these early research experiences have led to increased student outcomes, including increased academic success and enhanced scientific motivation.

12-1 Colin, SP*; Costello, JH; Sutherland, KR; Gemmell, BJ; Dabiri, JO; DuClos, K; Roger Williams University, Bristol, RI, Providence College, Providence, RI, University of Oregon, Eugene, OR, University of South Florida, Tampa, FL, CalTech, Pasadena, CA; *scolin@rwu.edu*

The role of suction thrust in the metachronal paddles of swimming invertebrates

An abundance of swimming animals have converged upon a common swimming strategy using multiple propulsors coordinated as metachronal waves. The shared kinematics suggest that even morphologically and systematically diverse animals use similar fluid dynamic relationships to generate swimming thrust. We quantified the kinematics and hydrodynamics of a diverse group of small swimming animals who use multiple propulsors, e.g. limbs or ctenes, which move with antiplectic metachronal waves to generate thrust. Here we show that even at these relatively small scales the bending movements of limbs and ctenes conform to the patterns observed for much larger swimming animals. We show that, like other swimming animals, the propulsors of these metachronal swimmers rely on generating negative pressure along their surfaces to generate forward thrust (i.e., suction thrust). Relying on negative pressure, as opposed to high pushing pressure, facilitates metachronal waves and enables these swimmers to exploit readily produced hydrodynamic structures. Understanding the role of negative pressure fields in metachronal swimmers may provide clues about the hydrodynamic traits shared by swimming and flying animals.

6-6 Collins, S; Zidek, J; Flower, N; Moore, M; Lambie, J; Thurmond,

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J; Oberle, B; Diaz-Almeyda, E*; New College of Florida; *ediazalmeyda@ncf.edu*

Follow the college student: The Florida Urban Microbiome Project

Today's students are part of a pivotal generation shaped by the climate crisis. Empowering them with a solid evidence-based worldview is key to creating a better future. Here we present a framework for engaging students, beginning with the development of a research project and ending with delivery of results back to the community. We started by identifying students' passions, skills, and interests and connecting with local organizations to find research opportunities. Students did research projects and collaborated with community stakeholders. We partner with -0-the Florida House Institute (FHI), a sustainable demonstration home in Sarasota, FL. FHI showcases ways for homeowners to improve home energy efficiency, land fertility, and watershed health. We formed the FL Urban Microbiome Project in response to a lack of understanding about how land management impacts the urban microbiome. Since then, our team has gained valuable data on soil characteristics, land management, plant diversity, and soil microbial community composition at FHI. Students devised sampling methods, conducted plant inventories, assessed management activities, sampled for soil microbial diversity, and measured soil carbon content. As a result, students documented that FHI's one-acre lot housed 98 unique plant species, displayed differential soil carbon storage across plant species and management types, and experienced drastic seasonal changes in soil bacterial communities. Students presented these findings to members of the community, gaining professional experience and broadening their career perspectives.

85-3 Collins-Jencarelli, C*; Green, L; Hranitz, J; Venn, C; Klinger, T; Bloomsburg University; *caitlyncollins6@gmail.com*

Thermal tolerances of the Caribbean sea urchins Eucidaris tribuloides, Echinometra lividis, and Echinometra lucunter (Echinodermata: Echinoidea): Potential impacts of climate change

With warming oceans, the physiological functions of organisms may be altered due to thermal stress. The sea urchins *Eucidaris tribuloides* and *Echinometra lucunter* are both ecosystem engineers. A laboratory study was conducted to measure the feeding rates and

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behaviors of *E. tribuloides* and *E. lucunter* at 26° C, 29° C, 32° C and 35° C. Feeding rates for *E. lucunter* or *E. tribuloides* did not differ (p=0.301) at different temperatures. Similarly, righting responses for individuals placed on their aboral surface did not differ (p=0.299) at different temperatures. Temperature affected the number of *E. tribuloides* able to right themselves at higher temperatures, starting at 32° C (p= 0.012), but not of *E. lucunter* (p=0.598). We conducted field studies in Honduras to determine natural environments inhabited by *E. tribuloides* and the congener *Echinometra viridis*. *Eucidaris tribuloides* showed a distinct association with rubble and an environmental temperature of 26° C (p=0.001). *Echinometra viridis* was found associated with rubble, *Millepora complanata*, *Montastraea annularis*, and *Agaricia tenuifolia* at temperatures ranging from 26° C to 29° C. *Eucidaris tribuloides* appears to be stenothermal in the lab and field whereas *E. luncunter* and *E. viridis* appear to be eurythermal in the lab and field, respectively. These results suggest responses by sea urchin communities to thermal stress will be complex because each species of sea urchin will be impacted by thermal stress differently. As a result, both community structure of and ecosystem services by sea urchins may shift dramatically with climate change.

12-7 Colón, DA*; Ford, MP; Santhanakrishnan, A; Oklahoma State University; *askrish@okstate.edu*

Dumb it down: A simplified metachronal locomotion mathematical model

Metachronal swimming is a locomotion strategy used by freely-swimming crustaceans such as krill. Krill and other crustaceans that use metachronal swimming paddle their swimming legs at Reynolds numbers ranging from approximately 10^1 to 10^4 dependent on body size and swimming behavior, where asymptotic methods used to analytically solve fluid dynamic problems do not apply. We developed a mathematical model of this locomotion strategy using a system of nonlinear ordinary differential equations. We approximate the swimming legs as pairs of two-dimensional hinged oscillating plates following simple harmonic trajectories with background flow equal to the body velocity. The model accounts for forces on the paddles and on the body to predict the general planar motion in the sagittal plane. Propulsive forces on each paddling limb are

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calculated using drag-coefficient models, where the relationship between drag force and the Reynolds number is obtained from 2D computational fluid dynamics simulations. The model is currently limited based on the assumption that the total force produced is the sum of the forces produced by individual paddles, neglecting any fluid dynamic interactions that could augment force. A comparison of the swimming speed predicted by the model to that of a robotic model will be presented.

BSP-7-10 Conkling, M*; Pomponi, SA; Harbor Branch Oceanographic Institute, Florida Atlantic University, Fort Pierce, FL; *mconkli2@fau.edu*

A sponge cell culture biobank for habitat restoration, biotechnology applications, and pharmaceutical development

Sponges (Phylum Porifera) are one of the most diverse and abundant benthic components in marine ecosystems. They provide important ecosystem services (e.g., water filtration, nutrient cycling, refuge for other organisms), and they are indicators of environmental conditions. But sponges are susceptible to diseases, abrupt cold-water events, and harmful algal blooms, resulting in massive sponge die-offs; in the deep sea, sponges can be destroyed or damaged from fishery and mining activities. We have recently reported rapid cell division of marine sponge cells cultured in optimized nutrient media and the first marine invertebrate (sponge) cell lines. This discovery forms the basis for the development of a biobank of cryopreserved sponge cells that can be used as a repository for sponge biodiversity, as well as to support future research in habitat restoration, biotechnology applications, and sponge-derived drug development. We have established a biobank of cryopreserved cells from more than 200 individual sponges, representing more than 50 species, 26 families, 15 orders, and 2 classes of shallow and deep water sponges. Of these, exceptionally rapid cell division rates (a two- to ten-fold increase in cell number in 48 hours) occurs in more than one-third of the species tested. This is the first bio-bank of living marine invertebrate cells. Research continues on optimization of nutrient media, as well as development of methods for culture scale-up.

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54-1 Constantin, ML*; Farina, SC; Gignac, PM; Uyeno , TA; Clark , AJ; Howard University, Oklahoma State University, Valdosta State University, College of
Charleston; *melissa.constantin@bison.howard.edu*

3D anatomical reconstruction of the feeding apparatus in Myxine using diceCT

Hagfish apprehend food items with cyclically protracting and retracting dental plates: an elaborate, bilaterally symmetric array of raptorial keratinous teeth mounted on thin, flat cartilaginous plates situated in the rigid anterior half of the hagfish feeding apparatus (HFA). Lying beneath the dental plates are robust cartilaginous basal plates, however, these rigid tissues collectively comprise only 15% of the total mass of the HFA. When feeding on large or tethered food items, seized portions of flesh can be forcefully retracted into the mouth. Retraction is powered by a muscular hydrostat located in the posterior half of the HFA. The hydrostat is cylindrical and contains three-dimensionally complex arrangements of longitudinal, semicircular, and transverse muscle fibers. Recently, diffusible iodine contrast enhancement micro-CT was successfully implemented in reconstructing the 3D morphology of the HFA in *Eptatretus stoutii*, a species from the subfamily Eptatretinae. Our goal was to reconstruct the 3D HFA morphology in representatives of the Myxininae: *Myxine hubbsi* and *M. glutinosa*. Using 3D slicer and Avizo software, we segmented the dental plates, palatal teeth, basal plate cartilages and the whole muscles comprising the muscular hydrostat. These data were compared to previously gathered data on *E. stoutii* and a metamorphosed sea lamprey *Petromyzon marinus*. The conserved morphology in the HFA across these hagfishes suggests these species procure functionally similar prey. Furthermore, the HFA contains significantly larger muscles and dramatically fewer supportive cartilages than the jawless feeding apparatus of metamorphosed lampreys.

50-8 Conway, SJ*; Kramer, EK; Harvard University, Cambridge, MA; *sconway0@gmail.com*

The long and short of it: the plant hormone brassinosteroid regulates petal spur length in Aquilegia by controlling cell elongation

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The model flowering plant Aquilegia produces elongated, three-dimensional petal spurs that fill with nectar to attract pollinators. Previous studies have found that the spur develops with two major phases, firstly cell division concentrated around the incipient nectary, followed by a secondary switch to cell elongation to produce the lengthened spur. This second phase of rapid, anisotropic cell elongation determines the final length of the spur, a character which shows surprising diversity within the genus. Transcriptomic studies on the petal spur revealed the upregulation of the Aquilegia homolog of BEH4, a known response transcription factor to the plant hormone Brassinosteroid (BR). In Arabidopsis and rice, brassinosteroids have been shown to regulate a wide range of developmental processes, including cell elongation. These data suggest that BR signaling may play a critical role in the switch from cell division to cell elongation that leads to the formation and length of the petal spur in Aquilegia. In this study we are investigating the role of BR transcription factors in the Aquilegia petal spur using a combination of gene expression studies, hormone applications and gene silencing.

80-9 Cook, A*; Pandhigunta, K; Didcock, RL; Castro, JT; Acevedo, MA; Walker, A; Acharya, R; Crofts, SB; Bhamla, MS; Anderson, PSL; Patek, SN; Ilton, M; Harvey Mudd College, Georgia Institute of Technology, University of Illinois at Urbana-Champaign, Duke University; *milton@hmc.edu*

Open-source software for modeling biological latch mediated spring actuated systems

A variety of organisms employ Latch Mediated, Spring Actuation (LaMSA) to achieve velocities, accelerations, and power outputs unmatched in either directly actuated muscle-driven systems or synthetic systems of a comparable size and repeatability. Previous efforts to model the mechanics of LaMSA systems have assumed linear constitutive relations for the system elements (spring, latch, and loading motor). We present a simplified ″toy model″ of LaMSA systems, and an associated open-source software package, that allows for the selection of different nonlinear forms for the constitutive equations of each element. The graphical user interface associated with our model also allows users to plot performance metrics across one- or two-dimensional cross-sections

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of the overall parameter space. This tool allows us to determine parameter space regions in which a LaMSA system is more effective than a purely motor-driven system. The nonlinear capabilities of the model allow us to better probe the properties of LaMSA systems than might be possible with linear models.

BSP-11-5 Coombs, E*; Clavel, J; Felice, R; Bennion, R; Beatty, B; Goswami, A; Park, T; Churchill, M; Geisler, J; University College London, Université Claude Bernard, University of Liège, NYIT College Of Osteopathic Medicine, Natural History Museum, The Natural History Museum, University of Wisconsin-Oshkosh, New York Institute of Technology ; *ELLEN.COOMBS.14@UCL.AC.UK*

Influences on cranial morphology in whales: Investigating the evolutionary history and diversity of the cetacean skull

Odontoceti (toothed whales) and Mysticeti (baleen whales) diverged ~39 Ma. Odontocetes evolved high-frequency echolocation and shifted cranial bones posteriorly, while mysticetes evolved larger masses and filter-feeding. Despite an excellent fossil record, little quantitative study of shape evolution spanning cetacean diversity has been done. Here, we quantify morphological disparity and evolutionary rate in cranial shape to identify the major factors driving its evolution, including ecological traits and palaeoclimate. We scanned 88 living and 111 Eocene to Pliocene fossil cetaceans, representing the largest 3D dataset for cetaceans ever constructed. We used 123 3D coordinate-based landmarks and 1905 curve semilandmarks to capture cranial shape and analyzed data within a phylogenetic framework. The largest component of cranial variation (PC1 = 41.6%) reflects a posterior shift in the nares, followed by rostrum length (PC2 = 23.0%) with dolichocephalic (e.g., *Pontoporia blainvillei*) and brachycephalic (e.g., *Kogia sima*) crania representing the extremes. After accounting for phylogeny, habitat had no significant effect on skull shape, but diet, feeding, and tooth type did. The highest morphological disparity is in the premaxilla and nasal, with the highest evolutionary rate (2 mult) in the frontal. Disparity rises rapidly in the Middle-Late Oligocene and peaks in the Middle-Late Miocene. A model with rate of cranial evolution tracking paleotemperature outperformed Brownian motion and Early Burst models and suggests highest rates in the Latest Eocene and Early-Mid Oligocene (during

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periods of global cooling) with a further peak in evolutionary rates during the Mid-Miocene warming period.

BSP-1-5 Coomes, CM*; Derryberry, EP; University of Tennessee Knoxville; *ccoomes@vols.utk.edu*

Some like it hot: Do female songbirds discriminate between songs produced under hot and cold temperatures?

Heat waves are increasing in number, length, and intensity around the globe, causing more animals to experience extreme temperatures. Small songbirds are particularly vulnerable to high temperatures as they are active during the day and produce a high amount of metabolic heat. One songbird behavior that has been shown to be impacted by high temperatures is song production. Often, male songbirds sing a species-specific song, which serves as a signal of quality to a potential mate. While it has been shown that male songbirds sing less when temperatures are higher, we do not know if the information contained within these songs changes. As an observer, it can be difficult to visually identify changes in birdsong, even when other birds can tell the difference. Therefore, the first step to test whether heat stress influences song salience is to ask the signal receivers: female songbirds. Here we tested whether 17 female zebra finches (*Taeniopygia guttata*) could discriminate between songs produced by males under heat stressed (43° C) and thermal neutral conditions (35° C). We found that male zebra finches reproduce their songs less accurately. While females exhibited a range of individual variation for songs produced under different temperature treatments, we found no evidence that our population preferred songs produced by males under thermal neutral or control temperatures.

38-10 Coon, T*; Peragine, P; Chase, HT; Tobalske, B; University of Montana, Montana State ; *teakettlebookshelf@gmail.com*

Un-sheathed: ungual vs. keratin structure and function in raptors

An accurate understanding of structures in extant taxa can be used to determine function and behavior in extinct species. Interpretation of the enlarged second pedal claw (C2) present in Dromaeosaurids, an extinct theropod, remains unclear despite multiple approaches that consider claw structure in extant birds.

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Using only the ungual bone of Dromaeosaurid fossils, information will always be lacking with regard to the functional morphology of a claw. But potential similarities can be understood between the claws of extant raptors and their extinct cousins if the relationship between ungual structure and sheath structure can be found. To analyze this relationship, we used high resolution microCT scans of C2 of five extant birds of prey (golden eagle, great horned owl, goshawk, osprey, red-tailed hawk). Measurements of the inner and outer curvature of both sheath and ungual, and the tip-to-tip length from sheath to ungual, were determined using longitudinal slices. Five cross-sectional slices were used to compare the ungual and sheath morphology along the length of the claw. High morphological variation was found across species. In cross-sectional shape, the eagle differed largely from both hawks, which may conflict with previous interpretations of dromaeosaur predatory behavior based on similarities to Accipitrid curvature. Some talons brandished sharp, ridge-like structures, which have previously not been described. Preliminary results demonstrate extensive and previously undescribed morphological variation between ungual and sheath structure across species. Ongoing work using 3D prints and mechanical tests of both sheath and ungual will provide better insight into the functional implications of this structural variation, as well as of unique features like the keratinous ridge.

36-2 Corn, KA*; Friedman, ST; Martinez, CM; Larouche, O; Price, SA; Wainwright, PC; Univ. of California, Davis, Yale University, Rice University, Clemson University; *kacorn@ucdavis.edu*

Feeding mode underlies the major axis of body shape diversity in reef fishes

The exceptional morphological diversity of reef-associated species is a long-appreciated feature of teleost fishes. However, the major factors that influence the body shape of reef fishes are poorly known. Feeding mode is a good candidate for affecting body shape, as it determines many aspects of a fish's life. We explored the effect of feeding mode on body shape in 1,530 species of reef fishes. We used a dataset of 8 linear measurements capturing body depth, width, and length using specimens from the National Museum of Natural History. Species were categorized by how they capture

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their prey, including those that capture most of their prey with direct biting actions on the substrate; species that capture prey only with suction; and species that regularly use both methods. A fourth category, ″ram biting” , included species for whom direct biting actions of the jaws play a major role in pelagic prey capture. We found that the major axis of body shape variation, which describes a spectrum ranging from eels to triggerfishes, aligns closely with a gradient associated with the method of prey capture. Attached prey biters and species that use both feeding modes have deeper, more laterally compressed body shapes. In contrast, ram biters typically have more elongate body shapes that are nearly absent among species that use any amount of attached prey biting. Furthermore, feeding mode affects diversity of body shapes, as suction feeders had nearly twice the disparity as the most exclusive biters or species that use both feeding modes. Our results demonstrate that transitions to any use of biting result in a deeper body shape, revealing that prey capture method is a major determinant of body shape in reef fishes.

92-10 Cornelius, JM*; Hahn, TP; Oregon State University, University of CA-Davis; *jamie.cornelius@oregonstate.edu*

Drivers of seasonal opportunistic breeding in the north temperate zone

Annual schedules reflect an evolved balance of survival and reproduction. Seasonality of food in the temperate zone is a strong selective force underlying scheduling in birds, and release from this through exploitation of non-seasonal food is presumed to have led to opportunistic breeding. Red crossbills (*Loxia curvirostra*) feed on conifer seeds that can persist through an entire annual cycle and are highly flexible in that they can often breed in the north-temperate winter. Prior research on one crossbill ecotype suggests that, despite this flexibility, crossbills remain seasonal in some important aspects of their reproductive physiology. Further, different ecotypes that forage on different conifers- including some that produce more stable seed crops - may display different temporal patterns of breeding in the wild. Here we show that while four different eco-types of red crossbill demonstrate some quantitative variation in winter breeding activity, they all exhibit clear bi-modal and highly seasonal breeding patterns. We

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discuss these results in the context of photoperiod, temperature and food to examine selective pressures on the evolution of opportunism in the temperate zone.

64-4 Cornelius Ruhs, E*; Becker, DJ; Oakey, SJ; Droke, HF; Ogunsina, O; Fenton, MB; Simmons, NB; Martin, LB; Downs, CJ; University of South Florida, Indiana University, Bloomington, Western University, American Museum of Natural History, SUNY College of Environmental Science and Forestry; *ecruhs@usf.edu*

Body size shapes immune cell proportions in birds and non-volant mammals, but not bats

Powered flight has evolved several times in vertebrates and constrains physiology in ways that likely shape how animals cope with pathogens and parasites. Understanding how the evolution of flight may inform relationships between body size and immunity could shed light on the ability of some taxa to harbor many virulent viruses without showing clinical disease. In this study, we used an allometric framework to quantify the scaling relationships between body mass and the proportions of two types of white blood cells, lymphocytes and neutrophils/heterophils, across 60 bat species, 414 bird species, and 256 non-volant mammal species. To do this, we combine data from (1) field studies of Neotropical bats, (2) published literature on other wild bat species, and (3) zoo-captive birds and non-volant mammals. Using phylogenetically-informed Markov Chain Monte Carlo generalized linear mixed models (MCMCglmm), we show that lymphocyte and neutrophil proportions do not scale with body mass among bats. By contrast, larger birds and non-volant mammals have higher heter-/neutrophil proportions, respectively, than smaller species in these taxa. However, flying endotherms (bats and 400 bird species) have disproportionately higher neutr-/heterophil proportions compared to non-flying endotherms (mammals and 14 bird species). Taken together, these results imply some differences between this aspect of cellular immunity in bats compared to birds and non-volant mammals.

75-5 Coughlin, DJ*; Santarcangelo, K; Wilcock, EB; Ellerby, DJ; Widener University, Chester, PA, Wellesley College,

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Muscle power production during intermittent swimming in bluegill

Locomotion is essential for the survival and fitness of animals. Fishes have evolved a variety of mechanisms to minimize cost of transport. For instance, bluegill sunfish have recently been shown to employ intermittent swimming in nature and in laboratory conditions. We focused on understanding the functional properties of the power-producing muscles that generate propulsive forces in bluegill to understand the implications of intermittent activity. We report on the muscle activity parameters (e.g. oscillation frequency, muscle strain, timing of activation) of the aerobic muscle of bluegill during intermittent swimming. We also used those parameters in muscle physiology experiments to examine muscle power output during intermittent vs. steady swimming in these fish. Intermittent propulsion involves swimming at relatively slow speeds with short propulsive bursts alternating with gliding episodes. The propulsive bursts are at higher oscillation frequencies than would be predicted for a given average swimming speed. The muscle physiology experiments demonstrated that intermittent activity allows muscle to produce sufficient power for swimming compared to imposed steady swimming conditions. This work lends support to the fixed-gear hypothesis that suggests that there are preferred oscillation frequencies that optimize efficiency in muscle use and minimize cost of transport.

88-6 Cowart, JR*; Collins, DM; Mignucci-Giannoni, AA; Alejandro-Zayas, T; Rivera-Guzman, AL; Larkin, IV; Aquatic Animal Health Program, University of Florida, Gainesville, FL, Department of Animal Sciences, University of Florida, Gainesville, FL, Caribbean Manatee Conservation Center, Inter American University of Puerto Rico, Bayamon, PR, Caribbean Manatee Conservation Center, Inter American University of Puerto Rico, Bayamon, PR; *jrc8462@ufl.edu*

First collection and characterization of semen in a West Indian manatee (Trichechus manatus)

While the West Indian manatee (*Trichechus manatus*) is one of the most well-studied sirenian species, there is limited information on many aspects of male reproductive physiology. Currently, no information on semen parameters exists in this species. Therefore, the aim of the study was to characterize semen parameters of

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ejaculates collected from a single West Indian manatee. A total of seven ejaculates were analyzed for the following parameters: volume, agglutination, pH, osmolality, viscosity, concentration, total sperm number, motility and kinematic parameters, morphology, plasma membrane integrity, acrosome integrity, chromatin condensation, and chromatin maturation. Of the samples, total and progressive motility were highest for ejaculates 2 to 5, exceeding 97% and 89%, respectively, but decreased in ejaculates 6 and 7. Sperm characteristics, including acrosome integrity (79.8%), chromatin condensation (93.1%), and chromatin maturation (99.5%) were high; however, large numbers of morphologically abnormal sperm were present (52.9%) and plasma membrane integrity was low (45.1%). While interpretation of the data is limited due to sample size, these results are the first of their kind for this species and provide preliminary insight into the reproductive physiology of male West Indian manatees.

17-2 Cox, CL*; Logan, ML; Florida International University, University of Nevada Reno, Georgia Southern University; *ccox@fiu.edu*

Using integrative biology to infer adaptation from comparisons of two (or a few) species

Phylogenetic comparative methods represent a major advance in integrative and comparative biology and have allowed researchers to rigorously test hypotheses about trait divergence in an evolutionary framework. However, phylogenetic comparative methods require trait data for many species, which can be impractical for certain taxonomic groups and trait types. We suggest that the philosophical principles of severity and strong inference can be employed in an integrative framework to infer adaptation in studies that compare only a few populations or species. This approach requires 1) ensuring that the study system contains species that are relatively closely related, 2) the formulation of a specific, clear, overarching hypothesis that can be subjected to integrative testing across the biological hierarchy (e.g., ecology, behavior, morphology, physiology, genetics), 3) the application of severe tests that avoid statistical underdetermination, and 4) the systematic refutation of alternative hypotheses. While difficult to collect for more than a few species, detailed and integrative data

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can be used to differentiate among several potential agents of selection. In this way, integrative studies of small numbers of closely related species can complement and even improve upon broad-scale phylogenetic comparative studies by revealing the specific drivers of adaptation.

80-3 Cox, SM*; DeBoef, A; Salzano, MQ; Katugam, K; Piazza, SJ; Rubenson, J; The University of California, Irvine, The Pennsylvania State University, University of California, Irvine; *suzannmc@uci.edu*

Restricting jumping during growth does not alter energy storage capacity

The storage and release of elastic strain energy can sidestep the force-velocity constraints of muscle. While energy stored in a muscle tendon unit depends on relative muscle and spring properties, we do not know whether muscle-tendon units (MTU) systematically adapt to functional demand. To test whether jumping during maturation alters adult MTU properties, we restricted jumping in a group of guinea fowl (Numida Meleagris, n=8) during growth. At maturity, we compared the jump performance of our treatment group to controls (n=8) and measured the morphological characteristics of the muscle, tendon and lever system of the gastrocnemius MTU. We found restricted birds jumped with lower takeoff velocities, yet there were no significant differences in the components of the elastic system between groups. Further, we quantified the energy storage capacity by measuring tendon potential energy when simulating 100% activation of the gastrocnemius muscle of a flock of subject-specific musculoskeletal models that integrated individuals' morphological measurements. We found no difference in energy storage capacity between groups or any correlation with experimentally measured jump performance. We conclude that gastrocnemius elastic system in the guinea fowl displays little to no plastic response to decreased demand during growth and that neural control of elastic systems may constrain performance more than morphology.

BSP-3-2 Crain, DD*; Karpovich, S; Quakenbush, L; Polasek, L; Baylor University, Waco, TX, Alaska Department of Fish and Game,

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Fairbanks, AK, Alaska Department of Fish and Game, Juneau, AK; *ddiancrain@gmail.com*

Using claws to compare reproduction, stress, and diet of female bearded and ringed seals in the Bering and Chukchi seas, Alaska, between 1953-1968 and 1998-2014

Rapid climate warming is decreasing sea ice thickness, extent, and duration. Marine mammals such as bearded (*Erignathus barbatus*) and ringed (*Pusa hispida*) seals may be negatively affected because they use sea ice for pupping, molting and resting. Claws from bearded and ringed seals store up to 14 and 12 years of sequential analyte data, respectively. In this study, we compare progesterone, cortisol, and carbon and nitrogen stable isotopes in female bearded and ringed seals during 1954-1968 (pre-1968, a period prior to sea ice decline) to 1998-2014 (post-1998, a period during sea ice decline). When comparing these periods, bearded seals had statistically higher cortisol concentrations post-1998, and for both species $\delta^{13}C$ was more negative post-1998. There was a positive relationship between progesterone and cortisol Z-scores for both species, except for ringed seals post-1998. A negative relationship between cortisol and $\delta^{13}C$ in bearded seals suggests a shift to higher prey diversity, possibly due to changes in sea ice in the Pacific Arctic evident post-1998. Progesterone Z-scores corresponded to expected differences among non-pregnant, unimplanted, implanted, and post-partum individuals. Using these data, pregnancy history was determined for reproductive years for each individual female sampled which could allow for yearly pregnancy rates to be calculated given a large enough representative sample of the population. These results combine decades of observational studies with chemical analytes to infer changes and connections in reproduction, stress, and diet.

22-2 Crane, RL*; Denny, MW; Stanford University, Stanford, CA; *rlcrane@stanford.edu*

Mussels maintain repair during chronic mechanical fatigue

Bivalve shells, like other hard external armors, protect not just from single, potentially shattering forces, but also from a lifetime of threats. Even non-lethal forces can weaken and damage shells through the process of fatigue. The long-term danger posed by these threats depends on the animal's capacity for repair, and

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their ability to maintain repair against ongoing threats. Therefore, we tested the ability of California mussels (*Mytilus californianus*) to repair damage from chronic fatiguing forces. Every week for seven months, we compressed live mussels for 15 cycles at a moderate force (~50% of shells' predicted one-time breaking force). We measured the final strength as well as the initial and final morphology of the fatigued shells and a group of non-fatigued control shells that were maintained under the same intertidal-simulating lab conditions. Despite months of fatigue, the fatigued and control shells did not differ in final strength. However, the fatigued shells were significantly thicker and had significantly more internal repair. These findings suggest that even a nonlethal fatiguing force, when chronic, can be sufficient to trigger a repair response, and that this response is sufficient to maintain shell strength. Maintenance of strength had consequences for shell shape, however. Fatigued shells showed significantly less increase in width compared to non-fatigued shells. In summary, mussels were able repair and maintain strength in response to ongoing mechanical threats, which is likely important to their success on exposed rocky coasts, surviving failed predator attacks and wave- and debris-caused damage. However, the long-term consequences of morphological changes associated with chronic damage and repair require further investigation.

BSP-2-7 Crawford, CH*; Cerrato-Moralse, CL; Webber-Schultz, AC; Hart, PB; Randall, ZS; Chakrabarty, P; Page, LM; Suvarnaraksha, A; Flammang, BE; New Jersey Institute of Technology, Rutgers University, Louisiana State University, Florida Museum of Natural History, Maejo University; *chc24@njit.edu*

Kinematics of terrestrial walking in balitorid loaches

Balitorid loaches exhibit morphological adaptations to living in fast flowing rivers and streams, including robust pectoral and pelvic girdles. These adaptations may also facilitate the terrestrial locomotion seen in the family. We collected high-speed video of walking in six balitorid species, *Balitora* sp., *Cryptotora thamicola*, *Homalopteroides* sp., *Homalopteroides modestus*, *Homalopteroides smithi*, and *Pseudohomaloptera sexmaculata* in the field, and one, *Homaloptera parclitella* in the

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laboratory. Videos were digitized using DeepLabCut (DLC), with 29 points digitized for each fish. Using the DLC output, we analyzed the duty factor, paired diagonal couplet overlap, fin rotation, body curvature, and distance (in body lengths) traveled over time and per step cycle. Walking performance varies among the balitorids analyzed here. The range of fin rotation for all species was greater in the pelvic fins than pectoral fins ($p<0.0001$ for each species). *Cryptotora thamicola* had significantly greater fin rotations than all other species in the pectoral fins while the greatest pelvic fin rotation was seen in *C. thamicola* and *Homalopteroides* sp. Duty factor was greatest in *C. thamicola* and all four species in the Balitorinae subfamily had a higher duty factor than the three Homalopteroidinae species. The same pattern between subfamilies was seen in the overlap between paired diagonal couplets. *Cryptotora thamicola* traveled the greatest body lengths per stride, although stride rate was lower than other species resulting in reduced body lengths per second. Here we examine the walking kinematics of recently collected balitorids and compare those with previous studies of terrestrial tetrapodal walking.

93-11 Cribellier, A*; Spitzen, J; Straw, AD; van Leeuwen, JL; Muijres, FT; Wageningen University, Wageningen, The Netherland, Freiburg University, Freiburg, Germany; *antoine.cribellier@wur.nl*

Escape flight performances of night-active malaria mosquitoes: the role of visual and airflow cues of an approaching object

Female malaria mosquitoes have to blood feed on humans for egg development. In response, humans have developed defensive behaviors and therefore mosquitoes need to avoid being swatted while seeking for a blood meal. But the evasive maneuver dynamics of mosquito has not yet been studied. In contrast, various other species of flying insects have been shown to have great abilities in evading threatening objects. These studies focused on how insects responded to visual or auditory cues, and the role of airflow produced by the approaching object has been mostly ignored. Because malaria mosquitoes are night-active, airflow cues and airflow induced passive maneuvers might be particularly important. Here, we studied how malaria mosquitoes Anopheles coluzzii use airflow to evade a rapidly moving object in low light condition. For this, we build a

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flight arena with a real-time insect tracking system and an automated mosquitoes swatter. By systematically changing light intensity in the arena and the swatter disk type, we tested how escape performance changed with variations in visual cues and airflow cues generated by the swatter. We found that mosquito escape velocities were higher in bright light condition and when the swatter generated high air movements. This suggest that mosquitoes do use both airflow and visual cues to trigger their evading responses. Finally, we investigated if those maneuvers are passively induced by the airflow.

S3-8 Crofts, SB; College of the Holy Cross ; *scrofts@holycross.edu*
What is the point of defensive spines?
Spines are ubiquitous in both plants and animals, and while most spines were likely originally used for defense, over time many have been modified in a variety of ways. These modifications may alter the mode of defense or may allow spines to serve entirely different functions. Here, we review the biomechanics underpinning defensive spine use and modification. In order to understand the biomechanics of spines as puncturing tools we will explore how both the gross morphology of a spine affects its puncturing ability, as well as more fine-scaled surface morphology. In addition to puncture, many spines also deliver toxins as a part of their defense. While these spines often depend on puncture as part of their function, the mode of toxin delivery will vary between organisms. In other cases defensive spines don't have to puncture at all in order to defend the organism. The defensive action of these non-puncturing spines may still stem from interactions with the predator, or the spines may interact with the environment to deter predation. In many fish, for example, spines serve to make the animal larger and therefore more difficult to swallow. In other cases, organisms that live or hide in burrows and crevices, like sea urchins, may use spines to wedge themselves in place and prevent predator access. Finally, in some cases, while spines still serve to deter predators they also have been modified to serve secondary functions unrelated to predation or defense. For example, some cactus spines have modifications that help facilitate clonal reproduction. Alternately the hollow spines of hedgehogs both serve to deter predators and can also act as cushioning from falls and impacts.

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35-4 Crowder, C*; Ward, J; Ball State University; *cjcrowder@bsu.edu*
Embryonic environmental cues alter behavioral responsiveness but not performance in larval fathead minnow (Pimephales promelas)
Environmental factors can link life stages through behavioral, morphological, and life-history carry-over effects. Such linkages are important because the experiences at one life stage may promote variation among individuals at a later life stage, with fitness consequences. Most studies conducted to date have focused on the transition between the juvenile and adult life stages. However, environmental cues during the egg stage also have potential to affect morphology and behavior later in life. Here, we examined whether fathead minnow embryos, *Pimephales promelas*, adjust their behavior in response to a predator cue during the egg stage, and how information learned as embryos contributes to behavioral variation in larvae. Newly-laid embryos were kept for 5 days in aged water (control; C), or in water containing olfactory cues of a piscivorous predator (predator treatment; P), or paired with minnow alarm cue (predator + alarm cue treatment; P+AC). Embryonic behavior (i.e., activity level) was measured on day 5, before hatching. Larvae were then reared until day 21 under control conditions and tested in factorial antipredator behavioral performance and responsiveness assays [3 embryonic rearing conditions x 3 test conditions (C, P, P+AC)]. Embryos reared in a perceived 'high predation risk' environment (P+AC) exhibited reduced activity compared to the other treatments. In addition, larvae differed in their responsiveness to predatory stimuli at 21 days of age. However, we did not detect an effect of the embryonic environment on the performance of antipredator evasive behavior. Findings indicate that embryonic learning may improve the ability of individuals to respond appropriately to changes in environmental context, without a corresponding change in the expression of specific behaviors.

49-6 Cruz, T*; Bower, C; Leese, JM; DeSales University, DeSales University ; *tc0159@desales.edu*
Effect of habitat quality on aggression in convict cichlid pairs

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For many animals, habitat quality is one of the most significant factors in determining access to resources and general safety, and becomes even more important when the habitat serves as a potential breeding ground. As a result, many animals invest a great deal of time and energy defending their territories from conspecific and heterospecific intruders that compete for suitable habitats. The convict cichlid (*Amatitlania nigrofasciata) is an aggressive member of the Cichlidae family in which monogamous pairs defend territories that include nest sites by chasing and harassing intruders. As such, we hypothesized that pairs may be sensitive to the quality of a given habitat and capable of altering their defensive behavior in response. To test our hypothesis, two different environments were created in experimental aquaria. A 'high-quality' tank contained an opaque PVC nest site that hid individuals and eggs/fry inside while a 'low-quality' tank had a clear PVC nest site with a visible interior. Subjects were given time to form pairs, and then assessed for their levels of aggression in one of the two habitat treatments by introducing a juvenile conspecific intruder. The number of aggressive behaviors (bites, chases, displays) demonstrated from each pair was monitored and recorded. Preliminary data suggests that convict cichlid pairs can adjust their defensive behavior and will invest less in defending a lower quality habitat than a higher quality one.*

107-9 Cubillos, CA*; Augustine, KE; Sinclair, BJ; Buckley, TR; University of Auckland, Auckland, Landcare Research, Auckland, Western University, Ontario, Landcare Research; *ccub151@aucklanduni.ac.nz*

Temperature, nutrition and life history among New Zealand stick insects

Temperature constrains the kinetics of enzyme-catalyzed reactions and shapes the performance of whole-organism physiology and life history traits. Additionally, the environmental temperature can set the boundaries to a species' distribution and abundance. Therefore, an integrative understanding of the mechanisms by which an organism can adjust its physiology and life history in response to thermal changes, is crucial to advance our knowledge of the observed ecological patterns. In this context, due to their phylogenetic and biogeographical history, New Zealand stick insects are an ideal

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study model. Despite their tropical ancestry, they occur on a wide altitudinal and latitudinal gradient, encompassing different temperate and alpine habitats. Here we estimate the thermal sensitivity of digestive efficiency and quantify the thermal reaction norm of growth rate and size at maturity, among different species of New Zealand phasmids. The preliminary results show that proteins are absorbed more efficiently around 10° C. This is consistent with the hypothesis that cold temperatures slow down the transit of food along the gut, allowing more time for digestion. On the other hand, among the four species studied, only *Acanthoxyla geisovii* reaches a larger size at maturity when its development take place at a colder temperature than individuals reared at a warm temperature. These results give valuable insights into the evolution of different life histories and physiological strategies that allowed stick insects expand their tropical ancestral habitats to temperate ones.

81-5 Cunha, F*; Gutiérrez-Ibáñez, C; Wylie, DR; Iwaniuk, AN; Univ. of Lethbridge, Canada, Univ. of Alberta, Canada; *felipebrcunha@gmail.com*

oculomotor nuclei size reflects behavior in nocturnal and diurnal raptors

Eye movements are a critical component of visually guided behaviors in animals. Although the control of these movements by cranial nerve nuclei is conserved across clades, species variation in visually guided behavior and eye morphology could lead to variation in the size of oculomotor nuclei. Here, we test for differences in the size of the oculomotor nuclei among bird clades that vary in behavior and eye morphology. The volumes and neuron numbers of the oculomotor (nIII), trochlear (nIV), abducens (nVI) and Edinger-Westphal nuclei were quantified across 60+ bird species. Our comparative analyses show that owls and New World vultures have relatively smaller nIII, nIV and nVI nuclei and hawks have relatively large nIII and nVI nuclei compared with other clades. The relatively small oculomotor nuclei of owls are likely due to their unique tubular eye shape, which markedly constrains eye movements to a few degrees at most. Hawks are somewhat unique among birds in that the retina has two foveae located centrally and temporally. Hawks need to visually target in pursuit of moving

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prey, and likely require binocular frontal vision upon the grasping of the prey. Such behavior is likely dependent on extensive eye movements, resulting in the evolution of an enlarged nIII. Although vultures are closely related to hawks and have two areas of specialization in the retina, the temporal area is not a fovea and has lower spatial resolving power. Vultures only scavenge carrion and therefore are unlikely to rely as much on extensive eye movements. We conclude that the relative size of the oculomotor nuclei reflects visually guided behavior in birds, but more data is needed on eye movements in birds to better understand the evolution of their visual system.

91-8 Cunha, TJ*; Pavón, A; Espinosa, F; García-Gómez, JC; Giribet, G; de Medeiros, B; Museum of Comparative Zoology, Harvard University, Cambridge MA, USA | Smithsonian Tropical Research Institute, Panama City, Panama, Departamento de Zoología, Facultad de Biología, Universidad de Sevilla, Sevilla, Spain, Museum of Comparative Zoology, Dept. Organismic and Evolutionary Biology, Harvard University, Cambridge MA, USA; *CunhaT@si.edu*

Population connectivity of an endangered gastropod across the Mediterranean

Dispersal capacity and population connectivity have direct impacts on species distributions and susceptibility to extinction, especially in the face of anthropological disturbance. *Patella ferruginea*, a Mediterranean giant limpet, was an abundant patellogastropod on rocky coasts throughout the western Mediterranean. Harvesting and habitat destruction have caused drastic fragmentation and reduction of its populations. *P. ferruginea* is an endemic species and the most endangered marine invertebrate in the Mediterranean. Here we sampled tissues of populations from the Strait of Gibraltar to Sardinia and Tunisia, and used ddRADseq to investigate the genetic structure along its current range. Contrary to expectations based on the relatively short larval phase and the fragmented nature of the distribution, populations have little genetic structure across more than 1500 km. We also use this genome-wide data to infer recent demographic changes. Our results offer a promising perspective for future actions towards recovering the species, such as translocating

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individuals to help restore areas where it has been locally extinct.

S7-5 D'Alba, L*; Jeon, DJ; Yeo, JS; Manceau, M; Shawkey, MD; Universiteit Gent, EON- Department of Biology, Gent, Yonsei University, School of Integrated Technology, Seoul, Collège de France, Center for Interdisciplinary Research in Biology, Paris; *liliana.dalba@ugent.be*

Optics and development of highly iridescent feathers: the case of hummingbird melanosomes

Color is a phenotypic trait of particular significance to birds, which are known for their diverse color signals and color-producing mechanisms including pigments, light scattering from nanostructured feather tissues and combinations of the two. Hummingbirds are a highly diversified lineage with bright, iridescent plumage colors. The physical bases of this bright coloration are the arrays of hollow, melanin-containing platelets (melanosomes) within feather barbules that produce color through multilayer interference. Almost nothing is known of either how these unusual melanosomes form or of how they are arranged into highly organized nanostructures. Such knowledge is critical to understand their evolution and may provide inspiration for new synthetic optically active materials. Here, we assembled a developmental time series of growing feathers and used optical and electron microscopy to determine the sequential steps of platelet development and self-assembly into organized layers. We show that hummingbird platelets contain air bubbles early in their development inside melanocytes and, surprisingly, expand up to four times their initial size before completion of development. Organization occurs through apparently passive mechanisms driven by the high density of melanosomes inside the highly flattened barbules. Three-dimensional reconstructions using electron tomography affirm the precise organization of these fully developed nanostructures. Our data, in conjunction with data from other species, suggest that diverse developmental pathways guide the production of highly derived pigment organelles and the nanostructures they create.

16-9 Dakin, R*; Moore, IT; Horton, BM; Vernasco, BJ; Ryder, TB;

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Carleton University, Virgnia Tech, Millersville University, Washington State University, Bird Conservancy of the Rockies; *roslyn.dakin@gmail.com*

Testosterone-mediated behavior shapes social networks in wire-tailed manakins

Social networks are ubiquitous in animals and humans. Variation in social network structure can affect many biological processes, from the spread of pathogens to the evolution of cooperation. Testosterone is a key mediator of social behavior and studies have established that testosterone can often influence how individuals interact with their social partners. We investigated whether testosterone could also predict group-level social network dynamics in the wire-tailed manakin (*Pipra filicauda*), a lekking bird in which males perform complex coordinated displays with other males. We used an automated proximity system to longitudinally monitor male behavior several leks and we collected repeated samples of each male's circulating testosterone. We found that social networks that were composed of high-testosterone dominant males were less specialized, less stable, and had more negative behavioral assortment. These results support our main hypothesis that hormone physiology can predict group-level dynamics. We also observed that larger leks with more interacting individuals had more positive behavioral assortment, suggesting that small groups may constrain the processes of homophily and behavior-matching. Overall, these results provide evidence that hormone-mediated behavior can shape the broader architecture of entire social groups, and that testosterone-mediated behavior can impede the evolution of stable cooperation.

BART-1 Dakin, R; Carleton University; *roslyn.dakin@gmail.com*

The scaling of behavior: insights into competitive and cooperative systems

From dodging collisions to choosing your friends, behavior provides a means for animals to respond to diverse challenges. In my group, we study the dynamics of behavior with the goal of understanding how behaviors work and how they have evolved. In this talk, I will present two examples from our recent work on competitive and cooperative birds. The first study focuses on the evolution of agility in hummingbirds - a group of birds that uses flight to

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compete for food and mates. By examining the performance of flight maneuvers within and across species, and how this variation scales with muscle performance and morphology, we gain insight into how maneuverability evolves. In the second part of my talk, I will shift to a species of bird that is more cooperative than competitive, and a different kind of problem: how does an individual's behavior change with the scale of the social network? This work focuses on wire-tailed manakins, a neotropical bird that (like us) cooperates to attain status. Although these two studies cover very different questions and approaches in biology, they both illustrate how patterns of scaling in behavior can help us understand the mechanisms that drive complex systems.

S10-12 Daniels, J*; Aoki, N; Havassy, J; Mushegian, N; Katija, K; Osborn, K; MBARI, Moss Landing, CA, National Museum of Natural History, Smithsonian Institution, Washington, DC; *joost@mbari.org*

Metachronal moves in the midwater: Swimming of the polychaete Tomopteris

Tomopterids are a family of highly-derived, holopelagic, gelatinous polychaetes found throughout the ocean. They are distinguished from other polychaetes by their lack of internal segmentation and chaetae, combined with large paddle-like appendages (parapodia). Paddling of the fleshy parapodia and lateral body movement allow these animals to swim with a strikingly elegant motion that is visually distinct from other swimming polychaetes, such as nereids. We collected living tomopterids using remotely operated vehicles in California's Monterey Bay National Marine Sanctuary, and used high-speed particle image velocimetry (PIV) and brightfield imaging to study their swimming kinematics. We found that during straight, forward swimming, thrust is generated by active paddling of the parapodia, as well as a forward-directed body wave. This body wave also increases the range of motion of the parapodia, resulting in increased advancement of the body per stroke. The characteristics of the stroke deviate from existing simplified metachronal models for polychaetes and crustaceans, and PIV measurements revealed fluid interactions between adjacent appendages. Compared to other marine polychaetes which tend to have smaller parapodia, the body wave in tomopterids provides less direct thrust, and locomotion is dominated by active paddling of parapodia. Compared to euphausiids,

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stroke angle and frequency were similar, but flexible appendages, planar body symmetry and the body wave result in distinct kinematics.

31-2 Danziger, AM*; Frederich, M; University of New England ; *adanziger1@une.edu*

Can eDNA be used to estimate biomass? A Case Study for Using Carcinus maenas

Environmental DNA (eDNA) has been proven as an effective tool for the detection and monitoring of absence or presence of rare and invasive species. Furthermore, eDNA analysis has been used to quantify biomass in vertebrates, particularly fish species. However, this has rarely been studied in invertebrates. This study tested whether eDNA can be used to determine the biomass of the world-wide invasive green crab, *Carcinus maenas*. In a controlled lab study, we tested how biomass affects the eDNA concentration collected in context of different biotic and abiotic parameters. Our data show that eDNA concentration did not correlate with biomass, as it did with vertebrate species. When incubating 1, 3, or 6 crabs in 4 gallons of sterile saltwater for 1 to 7 days no dose-response effect was observed. eDNA concentration peaked around day 3, indicating time-dependent shedding and degradation events affecting the respective data. Temperature, motor activity, and aggression levels were varied and were shown to also impact the concentration of recovered eDNA. Our results show that biomass, temperature, activity, and potentially many more parameters affect shedding and degradation rates for eDNA, which impact the recoverable eDNA concentration. Therefore, eDNA analysis cannot be used to reliably determine the biomass of the invasive invertebrate species *C. maenas*. Funded in part by NSF EPSCoR Maine eDNA grant# 1849227.

21-4 Darin, EA; California State University Long Beach and Cabrillo Marine Aquarium, San Pedro, CA; *emily.darin@student.csulb.edu*

Effects of bisphenol-A on the morphology and survival of larvae of the sand dollar Dendraster excentricus (Echinodermata, Echinoidea)

Bisphenol-A (BPA) is an ingredient in the majority of plastics produced today. When plastics enter aquatic environments, BPA can

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leach out and affect the development and physiology of marine organisms. Comparisons of temperate and tropical species suggest that temperature has an impact on the sensitivity of marine organisms to BPA, but this hypothesis requires further testing, ideally using a single species that can be reared in a wide range of temperatures. The sand dollar *Dendraster excentricus*, which inhabits shallow waters from Baja California to Alaska, is one such species. In this preliminary study, I aimed to understand the effects of relatively low BPA concentrations on the larvae of *D. excentricus*. I exposed embryos and larvae of *D. excentricus* to four treatment solutions (no additives, vehicle control, 50 µg/L BPA, and 500 µg/L BPA) for seven days. The two BPA treatment concentrations are higher than have usually been detected in coastal marine waters, but lower than most other studies of BPA effects on echinoderm development. After exposure, I measured larval midline body length and postoral arm length, survivorship, and the frequency of normal development. Midline body length, postoral arm length, survivorship, and the frequency of normal development all decreased in the presence of BPA, in a dose-dependent manner. Relatively low concentrations of BPA can thus have strong effects on the development of sand dollar larvae. Larvae of this species, which can develop over a temperature range of at least ~12-22 ° C, are thus a useful model for testing how sensitivity to Bisphenol-A (and possibly other pollutants) varies with temperature.

S6-2 Datta, SR; Harvard Medical School Department of Neurobiology, Boston, MA; *srdatta@hms.harvard.edu*

Defining neural principles underlying naturalistic behavior through Motion Sequencing

The Datta lab studies how natural behavior supports cognition. Here we describe a method that combines 3D machine vision with unsupervised machine learning, to characterize the underlying structure of mouse behavior. We refer to this approach as Motion Sequencing (MoSeq). Using MoSeq we have discovered that mouse behavior can be segmented into a fundamental set of components that we call "behavioral syllables." Each behavioral syllable is a brief and well-defined motif of 3D behavior that the brain places in into specific sequences via definable transition statistics (or

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behavioral "grammar") to flexibly create complex patterns of action. By characterizing mouse behavior in terms of its component parts, we can use our behavioral characterization technique to identify subtle differences in the pattern of motor output under different experimental conditions with an unprecedented level of sensitivity. By combining MoSeq with in vivo imaging of neural circuits in behaving animals, we have identified context-dependent neural correlates for the sub-second structure, and have identified the dorsolateral striatum as a key node for implementing naturalistic behavioral sequences. We have developed a closed-loop version of MoSeq that enables us to trigger optogenetic interventions based upon the expression of targeted syllable or sequences; using this system to pulse dopamine during the expression of targeted behavioral syllables reveals rules and principles that constrain naturalistic learning. We have also developed extensions of MoSeq that enable characterization of multiple animals in complex environments. These experiments demonstrate that MoSeq can serve as a quantitative prism useful for characterizing relationships between neural circuit activity and naturalistic behavior.

107-3 David, ZA*; Owen, MA; Durrant, B; Choun, V; Officer, K; Griego, M; Whiteman, J; Old Dominion University, Virginia, Institute for Conservation Research, San Diego Zoo Global, Free the Bears, Cambodia, University of Massachusetts-Amherst, Massachusetts; *zdavi008@odu.edu*

Metabolic rate of two co-existing Ursidae species: Asiatic black bears and sun bears

Metabolic rate is a fundamental property that reflects the total energy demand for all aspects of organismal function, from immune performance to reproduction. Metabolic rate scales allometrically with body mass and varies with diet, tending to be lower for herbivores and large-bodied insectivores, and higher for carnivores specializing in vertebrate prey. In this study, we are examining the resting metabolic rate (RMR) of two Ursidae species at the Cambodia Bear Sanctuary supported by Free the Bears and located within the Phnom Tamao Wildlife Rescue Center in Cambodia. We are focused on two species that are divergent in body size and life history traits - the Asiatic black bear (*Ursus thibetanus*) and sun

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bear (*Helarctos malayanus*). Asiatic black bears are larger (110 kg versus 50 kg for sun bears) and are less insectivorous than sun bears, suggesting that their RMR may be lower. However, RMR may also be affected by the climate at our study site. Asiatic black bears are primarily distributed in temperate regions and our study site is close to their most southern and tropical extent, whereas sun bears primarily occur in tropical regions and are thus presumably better-adapted to the study site climate. This raises the possibility that the warm climate at our study site may result in a higher RMR for Asiatic black bears. Using flow through respirometry we are collecting measurements of resting VO2 and VCO2 of both species at the Rescue Center. We are repeating measurements on the same individuals within field seasons to assess intra-individual variation, and between seasons (December, cooler; May, warmer) to test for seasonal variation.

51-3 Davies, SW*; Kanke, MR; Aglyamova, GA; Matz, MV; Boston University, Cornell University, UT Austin, UT Austin; *daviessw@bu.edu*

Heritability of dispersal-related traits and gene expression in a coral

Range shifts are one mechanism by which corals can escape the adverse effects of climate change. To determine if genotypes capable of longer-range dispersal could be selected for under climate change, we quantified additive genetic variation in *Acropora millepora* larval dispersal-related traits. Using twenty full-sib families, we estimated heritability of four phenotypic traits relevant to larval dispersal: responsiveness to settlement cue, rates of lipid and protein loss, and red fluorescence. Significant variation in settlement and fluorescence was observed, with mean broad-sense heritability >0.45. RNA-seq identified genes whose expression was associated with these traits and assessed gene expression heritability across life history stages. Many larval genes showed differential expression across sires and the strongest effects were observed in genes implicated in genome stability and stress response, a likely consequence of heritable variation in condition. Expression profiles associated with variation in settlement included receptor activity and cell surface components, suggesting the heritable variation in sensory machinery. Gene

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expression associated with larval red fluorescence indicated that redder larvae exhibited differential regulation of genes associated with growth, metabolism, and stress response. We are now in the process of analyzing gene expression profiles of recruits from these same coral families to determine if this heritability of gene expression of larvae is maintained across life history stages. Overall these data demonstrate that significant heritable variation is available within coral populations that may serve as fuel for natural selection shaping novel adaptations under climate change.

S11-8 Davis, MS; Oklahoma State University, Stillwater; *michael.davis@okstate.edu*

If you want to run with the big dogs, you need to not be so human

Dogs are some of nature's most capable athletes. When blessed with the appropriate anatomic form to facilitate exercise and the appropriate environment and opportunity for conditioning, they can perform exercise far in excess of all other domestic animals. A well-trained dog may have an aerobic capacity 4-5 times greater than an elite human athlete, and a dog's endurance capacity (when quantified as sustained caloric expenditure) may also be 4-5 fold greater than an elite human endurance athlete. Unsurprisingly, their specific exercise physiology is iconoclastic relative to other lesser athletes such as humans - a dog's superlative exercise capacity is in many instances due to having developed metabolic strategies that circumvent the "rules" that limit human performance. Probably the most unexpected finding is that despite years of belief that dogs were fat-adapted (excelled at burning fat to support their exercise), recent work has demonstrated precisely the opposite: a well-conditioned dog is highly dependent on carbohydrates to fuel their exercise, and their extensive physiological responses to improve exercise capacity are directed towards increasing the availability of glucose for skeletal muscle uptake. These responses not only include the expected increase in insulin- and contraction-sensitive glucose transporters (GLUT4), but also a 2.5 fold increase in the expression of constitutively-active glucose transporters (GLUT1). This corresponds to the 2.5 fold increase in insulin-independent glucose clearance previously reported in well-conditioned athletic dogs and illustrates the extent to which exercising dogs convert their basic metabolic

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machinery to consider exercise performance as their basal metabolic state.

9-2 Davis, AL*; Thomas, KN; Goetz, FE; Robison, BH; Johnsen, S; Osborn, KJ; Duke University, Natural History Museum, Smithsonian Institution, MBARI, Smithsonian Institution; *al.davis@duke.edu*

Hiding in the deep: ultra-black camouflage in fishes

In the mesopelagic and bathypelagic realms of the ocean there is little light from the sun, but light is provided by bioluminescent organisms. Unlike sunlight, which is diffuse, bioluminescent sources are directed, leading to surface reflections from transparent or mirrored animals that can reveal them to predators. Pigment-based camouflage can reduce surface reflection below that of transparent organisms by absorbing >99.5% of light. We assessed this possibility in 18 species of deep-sea fishes from seven orders. Of the 18 species, 16 had ultra-black skin (reflectance <0.5%). Ultra-black skin was found across the entire body in some species (e.g. Oneirodes sp.) but only on parts of the body, such as the gut, in others (e.g. Cyclothone acclinidens). In all 16 species, the skin had a continuous layer of melanosomes just beneath the basement membrane of the epidermis that lacked the unpigmented gaps found in other darkly colored fishes. Additionally, unlike most fishes, there was no reflective collagen between the melanosomes and basement membrane. Using electron microscopy we measured the size and shape of the melanosomes to determine if they exhibited similar geometry to other fishes. We found that the melanosomes in ultra-black fishes were larger and had a higher aspect ratio than melanosomes in other fishes. Computational modeling of melanosome layers confirmed that the melanosome geometry in ultra-black fishes is optimized to reduce reflectance. Compared to layers of typical fish melanosomes, simulated layers of ultra-black fish melanosomes have less than half the reflectance. This reduction in reflectance is predicted by a mathematical model to reduce the sighting distance of these animals by predators up to six-fold, making ultra-black skin a powerful form of camouflage in the deep-sea.

9-6 Davis, SN*; Clarke, JA; The University of Texas at

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Austin; *sdavis6@utexas.edu*

Carotenoid coloration in non-passerine birds and expectations of carotenoid expression in extinct Dinosauria

Carotenoids are among the most ubiquitous pigments that produce bright colors in animals, and create most of the vibrant yellows, oranges, and reds in living birds. While they are comparatively well characterized in the plumage of many species, these pigments are also common in avian bare parts (e.g. skin, beak) but their phylogenetic distribution has not been investigated. The instability of carotenoids, coupled with the difficulty of detecting them in skin, makes investigating their distribution difficult. However, insight into this distribution would have implications for understanding the evolutionary pathways of carotenoid acquisition in birds, as well as informing the search for this coloration in extinct dinosaurs. We investigate the expression of carotenoid-consistent color across tissue types in all extant, non-passerine bird species (n= 4,022) and include archelosaur outgroups in a phylogenetic framework. We also investigate how dietary carotenoid intake relates to tissue expression for a subset of birds. We find that expression in skin and non-plumage keratin has a 50% probability in the most recent common ancestor of Archosauria. Consistent with previous studies we recover multiple gains of plumage expression within neognaths. However, including carotenoid-consistent color in bare parts reveals that expression in these areas arises much sooner and more often in crown clade Aves. We also found that diets high in carotenoid content correspond to color expression in more body regions and tissue types. If carotenoid-consistent colorations are to be found in non-avian dinosaurs our results suggest they would most likely be found in bare skin regions with potential for further elaboration into keratinous tissues. However, carotenoids in non-feather structures in birds are less stable and can degrade rapidly, limiting their preservation potential.

6-1 Davis-Berg, EC*; Rafacz, ML; Columbia College Chicago, Chicago; *edavisberg@colum.edu*

Using zoos and webcams to incorporate research into an undergraduate animal behavior course

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Incorporating independent student research projects into the curriculum of survey-level biology courses can be a difficult task. In our non-majors animal behavior class we have developed a semester-long research project assignment that introduces, assesses, and applies many of the concepts covered in the class. This project can easily be adapted for non-majors biology, majors biology, or other more general survey classes, including remote classes in the midst of the global pandemic. The project involves a trip for data collection at our local zoo, additional data collection through the use of web cams, and writing of a scientific report. Students must use the scientific method to design their research project and formulate a hypothesis. Throughout the semester, students learn about different behavioral sampling methods and how to develop and use an ethogram in class using animal webcams from zoos. At the zoo, students conduct a comparative behavior project by collecting data from a main animal and two related animals. We use multiple trials so students can observe differences in behavior over time. Students then write a report after practicing data analysis and graphing in Excel and learn how to explain and interpret their own scientific data. This poster will explain how others can design and implement project-based learning in their class and will cover tips and tricks we've learned from our experiences over the years.

S12-7 Day, LB*; Harvey, MC; Helmhout, W; Olsson, U; Pano, G; Hoeksema, JD; Lindsay, WR; University of MS, Göteborg University; *lainyday@olemiss.edu*

Sexual selection for acrobatic courtship complexity drives increases in cerebellum volume and body size

Manakin males (Aves: Pipridae) attract females with acrobatic displays varying in complexity across species. Previously, we found that brain mass (BrM) and body mass (BdyM) increase with display complexity. We suspect the BdyM relationship is due to muscle hypertrophy and dense bones associated with acrobatics. If so, body size measured by tarsus length cubed (Tar^3) is unlikely to relate to complexity. We predict that BrM is driven by mosaic evolution of the the cerebellum (CB), which is essential for procedural learning, and the arcopallium (AP), a sensorimotor region that includes a motivation-linked limbic nucleus (taeniae, Tn). In 12

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manakin species and a closely related flycatcher, we measured the volume (Vol) of Br, AP, Tn, CB, and a visual thalamic nucleus as a control (rotundus, Rt). Brain regions were adjusted for bird size and these adjusted values and the raw values for BrVol and Tar^3 were corrected for phylogeny. Tar^3 and Vols of Br, CB, and AP but not Tn or Rt were each positively associated with display complexity. To determine which variables best explain variation in complexity, we ran 3 mixed models with two random effects; species and a phylogeny covariance matrix. The best brain region model included CB, AP minus Tn, Tn, and Rt; CB had a positive association and Tn had a negative association with complexity. While BdyM is positively associated with complexity, in models with Tar3 or BrM, it is redundant. Tar^3 is the best predictor of complexity, but BrM also predicts a unique portion of the variation in complexity. Phylogeny does not explain complexity. Thus, sexual selection for acrobatic complexity boosts the capacity for procedural learning via enlargement of CB Vol and increases Tar^3 size, possibly in relation to the link of Tar^3 with body condition.

98-7 Deakin, WJ*; Anderson, PSL; den Boer, W; Hill, JJ; Rücklin, M; Donoghue, PCJ; Rayfield, EJ; University of Bristol, Bristol, University of Illinois, Urbana, Swedish Museum of Natural History, Stockholm, Smithsonian Institution, Washington, DC, Naturalis Biodiversity Center, Leiden; *wd15899@bristol.ac.uk*

Theoretical functional morphology reveals morphological evolution of the first jaws tracks a Pareto optimal front

The Siluro-Devonian adaptive radiation of gnathostomes, which underpins almost all living vertebrate biodiversity, is characterised by the evolutionary innovation of the jaw. Previous work revealed stasis in jaw mechanics through the Devonian, following an initial burst in the late Silurian. Here we focus on the constraints on jaw morphology through the investigation of the form and functional performance of jaws across theoretical morphospace. This was achieved by generating a grid of theoretical shapes which encapsulates the range of early gnathostome jaw shape using Elliptical Fourier Analysis (EFA). The functional optimality of each shape was assessed based on resistance to stress and a metric of rotational efficiency, which were combined using a novel Pareto ranking framework. The resultant adaptive landscape was used

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to interrogate the patterns of jaw morphospace exploration in early gnathostomes. We find that the mandibles of early jawed vertebrates exhibit increasing morphological variance over time contrasting with static functional variety. Gnathostome jaws evolved from initial morphologies that were already optimised for stress resistance and speed of jaw closure, criteria incompatible with jaws evolving first to enhance ventilation. Later jawed vertebrate lineages expand into less optimal regions of shape space, possibly because of additional conflicting selection pressures, but most jaws are Pareto optimal. Functional constraints on early jaw evolution may have become more flexible through time.

BSP-3-8 Deal, CK*; Volkoff, H; Memorial University of Newfoundland; *ckdeal@mun.ca*

Response of the thyroid axis and appetite-regulating peptides to fasting and overfeeding in goldfish, Carassius auratus

The thyroid axis is a major regulator of metabolism and energy homeostasis in vertebrates. There is conclusive evidence in mammals for the involvement of the thyroid axis in food intake, but in fish, this link is inconclusive. In order to assess the effects of nutritional status on the thyroid axis in goldfish, *Carassius auratus*, we examined brain and peripheral transcript expressions of genes associated with the thyroid axis [thyrotropin-releasing hormone (TRH), thyrotropin-releasing hormone receptors (TRH-R type 1 and 2), thyroid stimulating hormone (TSH), deiodinase enzymes (DIO2, DIO3) and UDP-glucoronsyltransferase (UGT)] and appetite regulators [Neuropeptide Y (NPY), proopiomelanocortin (POMC), agouti-related peptide (POMC) and cholecystokinin (CCK)] in fasted and overfed fish for 7 and 14 day periods. We show that there was a strong response of the thyroid axis to overfeeding, with an increase of brain TRH and TSHβ expressions after 14 days. In fasted fish, hepatic DIO3 and UGT transcripts were down-regulated from 7 to 14 days, suggesting an increase in thyroid hormone degradation. Nutritional status had no effect on circulating levels of thyroid hormone. Central appetite-regulating peptides exhibited temporal changes in expression, with decreased expression of the appetite-inhibiting peptide POMC, and increased expression of the appetite-stimulating peptide AgRP, from 7 to 14 days for both fasted and overfed fish, with no change in NPY. Intestinal CCK

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expression was elevated in fasted compared to overfed fish, in contrast to the typical anorexigenic role of this peptide. These results indicate that nutritional status time-dependently affects the thyroid axis. Our study helps to fill a knowledge gap in current fish endocrinological research on the effects of energy balance on thyroid metabolism and function.

93-4 deCastro , N*; Marguerite, NT; Bernard, J; Harris, D; Cooper , RL; University of Kentucky. Lexington, KY, 520 Ruddles Mill Rd, Paris, KY; *ndecastro333@gmail.com*

Behavioral effects to heat in larval Drosophila with and without TRPA1 receptors in sensory neurons and the medicinal blow fly (Phaenicia sericata)

Larvae of Drosophila and other related insects, such as the medicinal blow fly (Phaenicia sericata), demonstrate a thermal preference. What drives the differences in behavioral response among species is not fully understood but is likely driven by evolutional adaptive pressures. Larval Drosophila melanogaster with over expression of genes coding for the TRPA1 receptor (i.e. the capsaicin or heat receptor) in sensory neurons are repelled by capsaicin or high heat (>28oC) whereas the non-over expressers show no behavioral response to capsaicin. The larvae of Phaenicia sericata are attracted to heat when placed in cold environment (10oC); however, this response is not as robust in larval Drosophila with or without over expression of the TRPA1 receptor. The larvae of P. sericata are attracted to heat over a food source when placed in a cold environment. Comparisons with larval Drosophila, with over expression of TRPA1 receptor, reveal robust avoidance of the heat or capsaicin. An interesting phenomenon occurs when P. sericata are placed at 4oC, they huddle which is not seen with Drosophila even when overexpressing the TRPA1 receptor. Is this an evolutionary survival skill for P. sericata to find decaying animal material and a cooperative group survival when exposed to cold?

110-7 Deconinck, AD*; Willett, CS; University of North Carolina at Chapel Hill; *aimeed@live.unc.edu*

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The odd un-couple: Hypoxia tolerance uncorrelated with acid tolerance in populations of Tigriopus californicus

Organisms living in the intertidal habitat must cope with co-occurring stressors as a result of daily fluctuations of exposure and submergence. Hypoxia (low oxygen) and low pH occur at the same time when the rate of photosynthesis is low and respiration is high, such as overnight. To test whether these correlated stressors resulted in correlated traits, we measured survival of adult *Tigriopus californicus* to acute hypoxia exposure or acute acid exposure. *T. californicus* copepods live in shallow pools of the high intertidal from Baja California to Alaska. Low levels of migration between populations has led to large differences in thermal tolerance at different latitudes. After testing copepods from 6 populations that spanned a wide latitudinal range, we found no correlation between hypoxia tolerance and acid tolerance at the population level, and further investigation into other predictors for stress tolerance such as sex, body length, and time since collection, were dissimilar for the two traits. Our results suggest that temporal correlation between hypoxia and low pH is less influential in driving coevolution of environmental stress tolerances than stressors that co-occur geographically.

BSP-7-8 Del Olmo, I*; Álvarez-Campos, P; Universidad Autónoma de Madrid; *irenedelolmob@gmail.com*

On the hormonal control of regeneration and reproduction in Pristina leidyi (Annelida)

Regeneration, the ability to replace lost body parts, is a widespread phenomenon in the animal kingdom that has been studied by biologists for a long time in a wide range of animals. This ability has been often connected to asexual reproduction, since the only difference between them appear to be the stimulus that triggers both processes. Hormones such as dopamine, melatonin and serotonin has been also related to control regeneration and asexual reproduction in many invertebrates. In particular, in annelids it has been proposed a hormonal control from the brain regulating both processes in a disjunctive way, but, up to now, any experiments with alive animals have been done. To shed light into this aim, we have investigated the hormonal control of these two trajectories in *Pristina leidy*, a freshwater oligochaete typically used as a

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model in developmental biology. The species exhibits huge regenerative abilities and routinely undergoes agametic reproduction by paratomic fission, i.e. the new animal is formed in the middle of a worm's body before detachment. Based on previous studies, we have morphologically characterized both trajectories into different stages, stablishing 4 stages for anterior regeneration, 3 stages for posterior regeneration, and 5 stages for asexual reproduction. Finally, we have tested the influence of dopamine, melatonin and serotonin hormones on the regulation of regeneration and fission of the specie. We have also considered some environmental factors, such as light conditions, that seems to be decisive in hormone synthesis and release of other invertebrates. Our preliminary results show that both regeneration and asexual reproduction are slow down or even completely inhibited in the presence of hormone and in darkness.

19-8 Delamare, IM*; Olson, RA; Provini, P; Center for Research and Interdisciplinarity (CRI); *irina.delamare@cri-paris.org*
How do birds modulate sound with their vocal tract?
Birds are able to produce a great diversity of sounds. They vocalize with a specific vocal organ, the syrinx, producing the primary vibration. However, it is not fully understood how the produced sound is filtered afterward by the vocal tract (trachea, upper part of the esophagus, oral cavity, and beak). We know that in songbirds, motions of the vocal tract help modulate the sound. When producing low pitch sounds, the throat and breast area expend visually, and the beak stays fairly closed. Conversely, while making high pitch sounds, the neck elongates and the beak opens widely. We hypothesize that all birds can filter the sound by changing the length and volume of their vocal tract. To determine how the different parts of the vocal tract modulate sound in songbird and non-songbird species, we filmed birds vocalizing with light cameras and synchronously recorded their sound with microphones to quantify the motions of the beak, neck, and pouch, while birds produced different sounds. Our results suggest a correlation between vocal pitch and the motions of the beak, neck, and pouch, supporting previous observations. This work shows that the complexity of bird vocalizations is not only related to the

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syrinx, but also to the entire upper vocal tract, which provides elements to better understand birdsong functional morphology.

68-4 Delaney, DM*; Hoekstra, LA; Janzen, FJ; University of Colorado Boulder, Oklahoma State University, Kellogg Biological Station; *david.delaney@colorado.edu*
Age predicts risky investment better than residual reproductive value in a long-lived vertebrate
Life-history theory predicts that investment into reproduction should increase as future reproductive opportunities (i.e., residual reproductive value, RRV) decrease. Researchers have thus intuitively used age as a proxy for RRV and assume RRV decreases with age when interpreting age-specific investment. Yet, age is an imperfect proxy for RRV and may even be a poor correlate in some systems. We used a 30-year study of the nesting ecology of painted turtles (*Chrysemys picta*) to assess how age and RRV compare in explaining variation in a risky investment behavior. We predicted that RRV would be a better predictor of risky investment than age because RRV accounts for variation in future reproductive potential across life. We found that RRV increased after initial reproduction for a few years, slowly decreased until midlife, and then steadily decreased to terminal reproduction. However, age predicted risky behavior better than RRV. This finding suggests stronger correlates of age (e.g., size) may be more responsible for this behavior in turtles. This study highlights that researchers should not assume that age-specific investment is driven by RRV and that future work should quantify RRV to more directly test this key element of life-history theory.

80-5 DeLap, SJC*; Rimkus, B; Shehaj, A; Taylor-Burt, K; Konow, N; UMass Lowell, Harvard U.; *Samuel_DeLap@student.uml.edu*
The effect of recruitment intensity on the plateau width of the muscle force-length relationship
Skeletal muscle powers joint movements via force production that is length-dependent. The force-length (FL) relationship is often measured from maximally activated muscle preparations, but muscles are rarely maximally recruited *in-vivo*. Increased joint range-of-motion and stride frequency that accompany increases in movement

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speed likely require muscle to produce greater force over a broader range of muscle-tendon unit lengths. Accordingly, we hypothesized that increasing activation duration, from a twitch (single stimulus) to a tetanic (train of stimuli) contraction, would broaden the plateau of the FL curve: the range of operating lengths where muscle reaches near-maximal force. We tested this hypothesis in two mouse hindlimb muscles, soleus and tibialis anterior, which differ in fiber type composition (slow vs fast), fiber architecture (parallel vs pennate), mechanical function (plantar vs dorsiflexor), and size (small vs large). To broaden our comparison, we also included muscles from other species (rat and duck). Our hypothesis was supported by evidence of increased FL plateau width from twitch to tetanic contractions in mouse soleus (n = 5, 38.1 ± 10.6%; mean ± S.E.M.) and tibialis anterior (n = 5, 22.7 ± 12.1%), as well as the rat medial gastrocnemius (n = 7, 17.9 ± 3.8%) and by preliminary results from duck lateral gastrocnemius (n = 1, 29.8%), both of which are large, mixed-fibered, and pennate plantar flexors. We anticipate these data from muscles with varying form and function to help determine if muscle structure, size, or function is the better predictor of FL plateau width.

S7-7 Delevoye, C; Institut Curie, PSL Research University, CNRS, UMR144, Structure and Membrane Compartments and Cell and Tissue Imaging Facility (PICT-IBiSA), 75005 Paris, France; *cedric.delevoye@curie.fr*

BLOC-dependent regulation of melanocyte pigmentation and its defects in the Hermansky-Pudlak Syndromes

Skin color and photoprotection depend on two epidermal cell types, melanocytes and keratinocytes. Melanocytes are the melanin pigment-producing cells and form a unique membrane-enclosed organelle, called the melanosome, in which melanin is synthesized, stored and ultimately transferred to keratinocytes. The biogenesis and function of the pigmented melanosome relies on membrane trafficking pathways, some of which are targeted in the Hermansky-Pudlak Syndromes (HPS) - a group of rare genetic disorders characterized by oculocutaneous albinism, excessive bleeding, and other systemic defects. Most of the genes that are mutated in HPS patients encode protein subunits of molecular complexes called BLOCs that play some roles in regulating trafficking pathways. However, the cellular and

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molecular functions of the BLOCs remain poorly understood. I will discuss here some of our recent studies illustrating how the BLOCs, particularly BLOC-1 and its partners, control membrane trafficking events in and out of the melanosomes. A better understanding of the cell biology of BLOCs elucidates how their malfunction leads to melanosome dysfunction in HPS, and could identify potential novel gene candidates targeted in uncharacterized forms of this syndrome.

57-8 Dempsey, BL*; Bidwell, JR; East Tennessee State University; *Dempseyb@etsu.edu*

Predator-avoidance response In larval black-bellied salamanders (Desmognathus quadramaculatus) to predator cues from native and nonnative salmonids

The introduction of nonnative salmonids into Southern Appalachia may pose a threat to resident salamander populations. In recent years, the stocking and encroachment of rainbow trout (Oncorhynchus mykiss) into headwaters where the black-bellied salamander (Desmognathus quadramaculatus) and brook trout (Salvelinus fontinalis) naturally coexist has raised concern. Black-bellied salamanders lack a strong evolutionary relationship with rainbow trout and likely lack the appropriate predator-avoidance responses. In aquatic prey, these responses are primarily influenced through the detection of chemical cues released from predators. The objective of this study was to determine how co-occurrence with a predator influences black-bellied salamander predator recognition. To evaluate this, salamander activity metrics were recorded before and after exposure to either native trout predator cue (brook), introduced trout predator cue (rainbow), or conditioned tap water (control). Larvae from different trout predator assemblages were tested and larvae all reduced their activity when exposed to brook trout predator cue, but their response to rainbow trout predator cue depended on their previous co-occurrence. Larvae from only areas with brook trout exhibited a weak predator-avoidance when exposed to rainbow trout predator cue. A follow-up test to determine the influence of alarm cue on predator response in these larvae indicated that the alarm cue enhanced the response to the rainbow trout predator.

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87-9 Deng, LC*; Edsinger, E; Salk Institute; *loladengc@gmail.com*
BUSCO-based phylogenomics resolves major cephalopod clades and placement of new pygmy lab models
Cephalopods have evolved sophisticated biological systems but how they are engineered and function is poorly understood. Cephalopod genomes and transcriptomes provide detailed lists of genetic components underlying cellular and anatomical parts and can yield novel hypotheses. Testing these ideas using genetic models may soon be possible, as different species are being explored, including pygmy octopus *Octopus chierchiae* and pygmy squid *Idiosepius paradoxus*. Understanding how their biological systems, parts, and components integrate in building and operation, or might relate to human, can be enhanced by comparative approaches. However, critical branches in the cephalopod tree are unclear, including pygmy octopus and pygmy squid. BUSCO gene sets represent gene families with typically a single member per species, making gene orthology calls more accurate. Newly-released BUSCO Mollusca HMMs offer identification of nearly 5,300 genes. To resolve deep branches in cephalopods and placement of new pygmy lab models, we have taken a BUSCO-based phylogenomics approach. We produced diverse cephalopod transcriptomes, including PacBio sequencing of pygmy squid and pygmy octopus, and, in combination with public data, leveraged maximum likelihood and Bayesian inference supermatrix and supertree methods. Transcriptomes were annotated by clustering and sequence features identified. Data are now available at the Cephalopod Sequence Evolution and Analysis portal, CephalopodSEA.io. Phylogenetic analyses place pygmy squid as sister to all other decapodiformes, while pygmy octopus are sister to blue rings, mimic octopus, *Octopus vulgaris*, and kin. This work provides an important tool for comparative and genomic approaches in cephalopods and for establishment of new pygmy lab models in development, physiology, and neuroscience.

2-13 Dennis, AB*; Inaebnit, T; University of Potsdam, Potsdam, Germany; *alicebdennis@gmail.com*
Physiological and genomic variation among cryptic species of a marsh snail (Melampus bidentatus)
The coffee bean snail (*Melampus bidentatus*) is a common detritivore in salt marshes on the US Atlantic coast. Using single gene

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sequencing, three cryptic species have been identified within *M. bidentatus*. Despite their high potential for dispersal as larvae, the three species have very different range extents, especially their northern limits. We are exploring physiological differences that may help explain this. Surprisingly, we have found that all three species have similar abilities to survive freezing conditions. We are now using tests of multiple stressors to examine the relationship between freeze tolerance and oceanic salinity. At the same time, we are using whole genome sequencing to more fully understand the relationship among cryptic species. Interestingly, karyotyping work from half a century ago suggests that chromosomal differences could exist between taxa.

S7-9 Deravi, LF; Northeastern University; *l.deravi@northeastern.edu*
Protein-pigment interactions facilitate dynamic color change in cephalopod chromatophores
Color is ubiquitous in nature; however, the ability to rapidly change color in response to environmental cues is unique to few biological systems and has captured the imagination of scientists and the public for decades. Cephalopods, including squid, octopus, and cuttlefish, are one such system that can rapidly camouflage in different underwater environments by employing a sophisticated ensemble of optical organs. While these animals have been a subject of research for many years, the fundamental physics and chemistry underlying their color modulation is still not well understood and the reality of creating a material that mimics such outstanding capabilities remains elusive. A recent study of their dermal chromatophore organ revealed an abundance of lens-crystallin proteins confined within nanostructured pigment granules, indicating a functional convergence between the eyes and skin of the animals that has yet to be explored. This talk will build off this exciting finding and discuss a potential role of these proteins in facilitating signal transduction during camouflage.

63-6 DeRogatis, AM*; Klasing, KC; University of California, Davis; *amderogatis@ucdavis.edu*
Evaluation of the trade-off between molt and innate immunity in the domestic chicken (Gallus gallus domesticus)

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Life history theory predicts that nutritionally costly life stages must be timed and balanced with the competing costs of self-maintenance. In birds, molt is known to be very expensive in terms of nutrient requirements due to the metabolic costs associated with producing high quality feathers quickly. The trade-offs between investments in self-maintenance and immunity are known to be important, but the relationship between molt and immunity remains unclear. Because both molt and the ability to mount an immune response are essential for survival, there is likely a trade-off wherein molt negatively impacts the ability of a bird to mount an immune response. The objective of this study was to use chickens (Gallus gallus domesticus) to clarify the impacts of molt on nutritional investment in immunity using an expensive innate immune system challenge. We used a 2x2 factorial arrangement of treatments (n = 7): 1) No molt control 2) No molt control + challenge 3) Molt and 4) Molt + challenge. To induce molt, chickens went from a long day schedule to a short-day schedule along with oral thyroxine. An injection of lipopolysaccharide (LPS) was administered three weeks after the onset of molt to initiate an acute phase response. Four hours after the LPS injection; tissue samples were collected for evaluation of cytokine expression using qPCR. Molt led to a significant increase in the size of both the spleen ($p < 0.001$) and the thymus ($p < 0.001$). Chickens undergoing molt generally had the lowest inflammatory response to LPS compared to the other treatment groups. This research clarifies the trade-off between molt and immunity and helps us understand one of the factors likely to motivate the variance in molt strategies among avian species.

8-4 Derryberry, EP*; Phillips, JN; Derryberry, GE; Blum, MJ; Luther, D; University of Tennessee, Texas A&M San Antonio, George Mason University; *liz@utk.edu*

Singing in a silent spring: birds respond to a half-century soundscape reversion during the COVID-19 shutdown

Actions taken to control the COVID-19 pandemic have conspicuously reduced motor vehicle traffic, potentially alleviating auditory pressures on animals that rely on sound for survival and reproduction. Here we evaluate whether a common songbird responsively exploited newly emptied acoustic space by comparing soundscapes and songs across the San Francisco Bay Area prior to

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and during the recent statewide shutdown. We show that noise levels in urban areas were dramatically lower during the shutdown, characteristic of traffic in the mid-1950s. We also show that birds responded by producing higher performance songs at lower amplitudes, effectively maximizing communication distance and salience. These findings illustrate that behavioral traits can change rapidly in response to newly favorable conditions, indicating an inherent resilience to long-standing anthropogenic pressures like noise pollution.

82-4 DesJardins, NS*; Fisher, AL; Harrison, JF; Smith, BH; Arizona State University; *ndesjard@asu.edu*

A common fungicide, Pristine®, impairs olfactory associative learning in honey bees (Apis mellifera)

Honey bees are exposed to agrochemicals such as insecticides, fungicides, herbicides, and spray adjuvants while foraging on treated crops. Fungicides have traditionally been considered bee-safe as they are designed to target the basic biochemical processes of fungal cells, but recent studies have suggested that they can cause death and, at lower concentrations, sublethal effects on bee behavior and physiology. Here, we focus on the fungicide Pristine® (active ingredients: 25.2% boscalid, 12.8% pyraclostrobin), which is sprayed during the blooming period on a variety of crops, and is known to poison honey bee mitochondria at ppm levels. We tested whether chronic consumption of pollen containing Pristine®, at a range of field-relevant and higher concentrations, impairs olfactory associative learning in honey bees. Learning performance was reduced at higher but not lower Pristine® doses, with negative impacts occurring within the higher range of concentrations measured in the field. We next exposed bees to Pristine® at larval, adult, or both life stages. We found that significant suppression of learning performance occurred when bees were exposed during both larval and adult life stages, and non-significant reductions occurred when they were exposed during only one stage. The reductions in learning could not be explained by effects on hunger or motivation, as sucrose responsiveness was not affected by Pristine® exposure. Our study provides strong evidence that Pristine® impairs olfactory learning, potentially affecting the foraging and pollination capacities of bees and raising renewed

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concern that standard methods to test the toxicity of agrochemicals to pollinators may need to be reevaluated. Supported by USDA-2017-68004-26322.

90-3 Desplat, Y*; Warner, JF; Smith, E; Vijayan, N; Blackwelder, P; Lopez, JV; Nova Southeastern University, Fort Lauderdale, FL , University of North Carolina at Wilmington, Wilmington, NC; *yvain.desplat@gmail.com*

Physiological and genetic effects of deepwater horizon oil and dispersant on a developing marine sponge model (Cinachyrella sp)

Sponges (Phylum Porifera) have shown to be bio-accumulators of heavy metals, and bio-monitors for polychlorobiphenyl (PCB) contaminants. Furthermore, marine sponges fulfill many ecological functions on reef ecosystems. However, very little is known about sponge behavior in the face of environmental changes. Consequently, we report a study to develop the Caribbean reef sponge Cinachyrella spp. as a viable experimental model organism. Stemming from the Deepwater Horizon oil spill in 2010, we designed an experiment to expose 24 individual sponges to sublethal amounts (0.5 ppm) of oil (WAF), oil mixed with 10% COREXIT 9500 dispersant (CE-WAF), and dispersant only. Light and electron microscopy observations showed evidence of physical changes and the presence of oil droplets trapped in sponge mesohyl. RNA-Seq determined the corresponding differential gene expression (DGE) response of the same samples of Cinachyrella. Overall, 31,571 total sponge transcripts were eligible for genetic profiling by RSEM and DESeq2 after annotating based on the Amphimedon queenslandica genome. Also, 12,913 transcripts displayed significant DGE. Differentially expressed transcripts included heat shock proteins, cell integrity proteins, cancer related proteins, and apoptosis related protein among others. Major genetic responses to oil started after 1 hour of exposure and higher DGE response was seen after 24 hours of exposure for dispersant and oil:dispersant mixtures. CE-WAF Oil:dispersant mixtures appeared most harmful to the sponge after longer exposure This study confirmed Cinachyrella as a suitable research model organism from Florida reefs.

18-2 Di Santo, V*; Lauder, GV; Stockholm University, Stockholm,

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Feeding affects individual and collective behavior of schooling fish

Schooling is a prevalent collective behavior that arises from the interaction of a group of individuals during swimming. School formations are characterized by strong polarization, and fish maintain reasonably discrete relative positions within the group. Schooling behavior may facilitate foraging, but to date there is little work on the interactions of individuals during the introduction of food. In this study we quantified tridimensional schooling patterns and dynamics in schooling fish, the Inland silverside (*Menidia beryllina*). Schools were composed of 14 individuals (average length = 5 cm) swimming at 15 different speeds, ranging from 1 to 8 body length per second. Three high-speed cameras recorded fish positions before, during and after feeding events to obtain a tridimensional reconstruction of fish movement using DeepLabCut. When food was introduced in the flow tank, the school formation was disrupted as silversides moved about to acquire individual food items. We quantified this repositioning of individuals within the school after feeding. Fish that obtained food tended to move to the front of the school where energetic costs of swimming are higher. We compared feeding events and repositioning of individuals at different flow speeds and found that schools are not static units, as fish change position rather often to acquire food, or to save energy by swimming behind other individuals. Changes in individual behavior and the interactions among individuals in response to food provide insights into the effect of local movement on general dynamics in collective behavior.

39-9 Diamond, KM*; Kwon, RY; Maga, AM; Seattle Children's Research Institute, Seattle, University of Washington,
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Measuring craniofacial variability in zebrafish using computational anatomy

Computational anatomy (CA) approaches start by estimating a canonical 'template' from a sample of images. This template is then used as a basis for statistical analysis to quantify

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structural differences among groups of interest. Here we apply CA to a sample of zebrafish with mutations in *bmp1a* and *plod2* genes, which are associated with human brittle bone disease, and their unaffected siblings. Due to the complexity of fish skulls, previous attempts to classify craniofacial phenotypes have relied on qualitative features or 2D landmarks. In this work we aim to quantify 3D craniofacial phenotypes of zebrafish by comparing mutants to their wildtype siblings. We first estimate a 'normative' zebrafish template using microCT scans of the unaffected littermates as the sample pool using the Advanced Normalization Tools (ANTs). To validate the accuracy of the template and our CA pipeline, we compared the otolith volumes from the template CA approach to manually segmented volumes of the same set of zebrafish. Our CA based segmentation volumes are statistically indistinguishable from our manual segmentations and show that both mutants have larger otoliths than their wildtype controls. We are currently in the process of using the canonical template as a reference to conduct fully automated 3D shape analysis of our samples. Preliminary results suggest that phenotypic differences in both mutants are concentrated in the posterior portion of the frontal bone and in the dentary. We expect these methods will greatly improve the 3D analysis of the complex fish craniofacial phenotypes, especially those of zebrafish which are an important model system for testing genome to phenome relationships in the study of development, evolution, and human diseases.

61-4 Diamond, S; Case Western Reserve University; *sarah.diamond@case.edu*

Constraints on specialist butterfly species range shift responses to recent climate change

Under recent climate change, many species are rapidly shifting their geographic ranges. Although there is a general trend toward poleward and upslope geographic range shifts, there is still considerable variation in the magnitude and even direction of contemporary range shifts. Theory suggests that specialization might constrain range shift responses. We tested this idea using a long-term monitoring dataset of butterfly range dynamics. Specifically, we examined associations between the magnitude and

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direction of range shift responses and degree of specialization. Overall, we found broad support for a trade-off between the magnitude of the range shift response and degree of specialization. Further, we found evidence that range position, relative to the location of the monitoring sites in the Midwestern United States, also explained variation in the range shift response. In effect, range dynamics were different at the leading versus trailing range edges. Our results suggest that species-level traits such as ecological specialization, and consideration of population-level responses at leading versus trailing range edges, can help to resolve variation in range shift responses to recent climate change. Such associations could further aid in predicting where species might be found in the future as the environment continues to change.

23-5 Diaz, C*; Aaron, E; Long, JH; Vassar College, Colby College; *cdiaz@vassar.edu*

Moth-catching by spiders: the spreading behavior of capture glue depends on the morphology of moth scales

One subfamily of moth-specialist spiders, Cyrtarachninae, have evolved a situational superfluid exhibiting extraordinary strength and dynamic hyper-spreading ability, but only when in contact with the scaled integument of moths. How does this predatory system work to defeat the scale-shedding defense of moths? We hypothesize that the key feature is the 3D topology of the scales on the integument: a microscopic meshwork of branching channels. Employing a microfluidics approach, we model the glue as it flows upon the surface of the scales, permeates the surface, and then flows within the scale meshwork. Using high-speed videos of spreading, we compare expected and observed spreading rates of the leading edge of the glue droplet; simple expectations about the spreading rate can be generated from Tanner's Law for the flow of a droplet on a surface, the Hagen-Poiseuille equation for flow in a pipe, and Darcy's Law for capillary flow. We found that interaction between the glue of Cyrtarachninae spiders and moth scales leads to a spread over distances far greater than those of common orb-weaver glues. We predict this continued spreading is sustained by the microfluidic forces of the meshwork and aided by the large droplet

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size of Cyrtarachninae spiders. This work is supported by the National Science Foundation under Grant No. 2031962.

74-8 Diaz, K*; Chong, B; Ding, JL; Lu, H; Goldman, DI; Georgia Tech; *kelimar.diaz@gatech.edu*

C. elegans maneuvering strategies in heterogeneous environments

Slithering animals (e.g., snakes, nematodes) generate and propagate waves along their elongated body in order to traverse highly damped environments. In particular, the mm-long nematode worm *C. elegans* must execute complex behaviors in other to navigate its natural environment (e.g., rotting fruit) and overcome heterogeneities. Specifically, the worms are able to generate a time-dependent omega-like shape (known as omega turns) that allows them to achieve high in place rotation. Yet, few studies have focused on how the worm generates and controls body waves of curvature for self-propulsion in complex environments. To discover principles of nematode control, we conducted experiments in fluid filled PDMS multi-post array - a model heterogeneous environment. Surprisingly, the worm was not hindered by the heterogeneities when performing turns. Instead the worm was able to perform omega turns by wrapping its body around the obstacles. Performance was comparable to that of on the surface of homogeneous agar or buffer, where the worm was able to achieve high rotation while minimizing the swept area. Preliminary experiments with mechanosensing defective mutants (mec-4) suggest that worms do not need to sense their surroundings to perform turns in complex environments. Our results suggest omega turns are a robust strategy to turn and maneuver in a myriad of environments.

24-12 Diaz, K; Robinson, TL*; Ozkan-Aydin, Y; Goldman, DI; Wan, KY; Georgia Tech, University of Exeter; *trobinson89@gatech.edu*

Minimal robophysical model for multi-flagellate propulsion

Microorganisms with appendages (e.g., flagella) have diverse strategies to locomote in highly viscous environments. Developing micron sized robots has become of interest to model the diverse locomotive behaviors. Yet, developing a microrobot without the use of external actuation (e.g., magnetic field) remains a challenge. To model low Reynolds swimming, we developed macroscopic

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robophysical models (body length of 3.87 cm) with the capability to generate self-driven movement in viscous fluids (mineral oil, 1,000 cSt). Our robots have four appendages that are independently actuated, designed to capture aspects of unicellular quadriflagellate algae. While different species of quadriflagellate algae share similar morphology, they exhibit differences in swimming speeds. We posit this is due to differences in their appendage coordination (e.g., gaits). We measured swimming performance in three distinct gaits, the pronk, the trot, and the gallop, and tested the effects of appendage orientation relative to the cell body. When the flagella were oriented perpendicular to the body, the robot achieved a speed of 0.020-0.1 body lengths per second depending on the gait. Results are comparable to microorganisms' performance, in particular the trot enables a higher speed than the pronk and the gallop. When the flagella were oriented parallel to the body, swimming performance decreased significantly for all gaits. Our results show that a minimal robophysical model has significant potential for understanding the control principles of low Reynolds swimming as seen in unicellular microorganisms.

33-4 Dickerson, HEW; Rivera, HE; Davies, SW*; Boston University; *haydendu@bu.edu*

Hot and bothered: Determining the effects of heat and starvation stress on oculina arbuscula corals

Coral reefs are among the most biodiverse environments on the planet. With the looming threat of irreversible climate change, understanding their tolerance to environmental stressors is key to conserving them. Corals rely on heterotrophy and carbon transfer from autotrophic algal symbionts to survive. Heat stress can interrupt this transfer in a process known as bleaching. Most corals are obligate mutualists, but some are facultatively symbiotic and can live without symbionts. These rely more heavily on heterotrophic carbon, a source shown to facilitate coral survival during bleaching events, especially when their algal symbionts are in low abundance. Here, we test the interactive effects of thermal stress (18-31° C ramp over 3 weeks) and heterotrophy on the facultatively symbiotic coral, *Oculina arbuscula*. We quantified photosynthetic efficiency of the algae's

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photosystem II with Pulse Amplitude Modulated (PAM) fluorometry throughout the 21-day experiment. To understand host response to the treatments, we also quantified total host protein and carb reserves, as well as protein levels of the immune response gene NF-κB. We find that heat stress leads to reduced symbiont density, but reductions are less pronounced in fed corals. We also find that PAM data correlates well with overall symbiont density and that photographic analyses of coral color corroborated these values. Heat stressed and starved corals showed the strongest induction of NF-κB protein levels with a 14-fold increase in protein levels compared to starved controls. Fed and heat stressed corals showed a 6-fold increase in NF-κB levels compared to starved controls. Overall, we find that heterotrophy can mitigate the effects of temperature stress, furthering our understanding of the role heterotrophy plays in coral stress response in facultatively symbiotic species.

27-7 Dimitrie, DA*; Benard, MF; Case Western Reserve University; *dad125@case.edu*

A comparison of the effects of two anuran competitors on breeding site selection in a treefrog

By breeding in environments with few competitors or predators, animals can increase the survival and growth of their offspring. However, the ability of adults to detect the presence of and distinguish between different species represents a potential limitation to adaptive habitat selection. We tested if the eastern gray treefrog (*Hyla versicolor*) changed its oviposition site selection in response to the presence of tadpoles of two other frog species: the American bullfrog and the green frog. We selected these species because, although they may both occupy treefrog breeding habitats, ecological differences suggest they may have different effects on treefrog tadpoles. We established three types of artificial breeding pools: no competitors, bullfrog tadpoles present, and green frog tadpoles present. Adult treefrogs bred in pools with no competitors more frequently and earlier in the breeding season than pools with competitors. There was no difference in breeding activity between pools with bullfrog and green frog tadpoles. An additional experiment revealed that treefrog tadpoles developed faster and grew larger in the absence

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of these competitors compared to the presence of either competitor. Bullfrogs and green frogs had similar effects on treefrog tadpole development and growth. Both competitors elicited a similar response in treefrog breeding site selection and resulted in similar effects on offspring fitness. These results contrast with previous studies suggesting a closely related treefrog does not avoid breeding in wetlands with heterospecific competitors. Our findings support a causal relationship between habitat selection and competition, and suggest that these two anuran competitors, despite their ecological differences, are functionally equivalent in their effects on amphibian breeding activity.

28-5 Dittrich , MC*; Dobkowski, KA; University of Alaska Southeast and Friday Harbor Labs, University of Washington, Bates College and Friday Harbor Labs, University of Washington; *mcdittrich@alaska.edu*
Feeding preferences of Pugettia producta on macroalgae species along the coast of San Juan Island, Washington
In the Salish Sea, beds of the only canopy forming kelp, *Nereocystis luetkeana,* vary in their density and distribution; the reasons behind this variation are still being explored and may vary by geographic location. Kelp forests provide important three-dimensional habitat to a wide array of species, but key organisms of interest that may influence kelp distribution and abundance are herbivorous grazers, such as the Northern Kelp crab, *Pugettia producta*. *P. producta's* feeding preferences, although observed with other macroalga species in a laboratory setting, are not well understood, as is their potential effect on *N. luetkeana* populations in the field. In other geographical locations of *P. producta's* range, they have been observed to consume a variety of different macroalga's. In the Salish Sea, it is not known if *P. producta* living in this region prefer the same macroalgae as others of the same genus and species. I conducted laboratory feeding trials to determine if a feeding relationship was present between the crabs and locally abundant macroalgae using a block design with the crabs as blocks. I ran three separate feeding experiments: vegetative *N. luetkeana* vs reproductive *N. luetkeana* (sori), *Egregia menziesii* vs *Sargassum muticum,* and *E. menziesii* vs vegetative *N. luetkeana*. *P. producta* consumed 3x more *N. luetkeana* sori then vegetative blade and did not show a

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significant preference for any other food source offered. A better understanding of *P. producta's* feeding preferences will inform future conservation and restoration plans to help keep *N. luetkeana* beds flourishing for years to come.

45-2 Dolinar, DP*; Edwards, MS; San Diego State University; *dillonpdolinar@gmail.com*

The zombification and revival of purple sea urchins (Strongylocentrotus purpuratus) in response to food availability

Purple sea urchins (Strongylocentrotus purpuratus) are herbivores who inhibit rocky reefs from British Columbia to Baja California. When top down pressure decreases, often by means of a decrease in predator abundance, purple sea urchins increase grazing intensity and are capable of consuming all of the macroalgae within a kelp forest. This has resulted in the formation of urchin barrens throughout the large portions of their range. In barrens, urchins experience starvation, causing physiological changes such as a decrease in gonad mass and, over time, a complete resorption of their gonad tissue. We examined how S. purpuratus responds metabolically when deprived of food for long periods of time. This was done by comparing respiration rates of urchins who had access to food and urchins who have been starved for seven and 14 weeks. We observed a significant decrease in oxygen consumption after the urchins were starved, indicating decreased metabolic activity. After 14 weeks of starvation, the urchins were again fed for seven more weeks, which resulted in a revival of their metabolic activity that matched pre-starvation levels. In addition, we sampled urchins from Stillwater Cove, CA from areas of high macroalgal density as well as barren areas but found there to be no difference in urchin metabolic rates between the two areas. Our results suggest that when facing starvation, urchin metabolic rates significantly decrease. However, if they periodically receive food, they can sustain moderate levels of metabolic activity.

S1-3 Dominoni, DM*; Visser, ME; Spoelstra, K; University of Glasgow, Netherlands Institute of Ecology; *davide.dominoni@glasgow.ac.uk*

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The effects of experimental light pollution on behaviour, physiology and fitness of a wild songbird

Associated with increasing urbanization worlwide, artificial light at night is increasingly recognized as a threat to wild animals. In birds, light pollution has been shown to affect behaviour and physiology. However, most field studies so far have been correlational and short-term, thus it is unclear if light pollution can ultimately affect fitness and population size. Here we present a comprehensive study on the long-term effects of light pollution on the great tit (Parus major), a songbird common in European cities. We used an experimental approach in the field where lamp posts with LED of different colors (white, green and red) were installed in previously dark forests in the Netherlands. Using a 8-year dataset of breeding events, mark-recaptures, behavioural and physiological data, we first show that exposure to experimental light pollution in the field result to changes in energy expenditure, nocturnal activity, spatial movements, susceptibility to infection and availability of caterpillar preys. Most of these effects were color-dependent, with white and green light having stronger effects than red light. However, behavioural and physiological changes were not followed by fitness effects, as reproductive output and survival probability were not affected by any of the light types. This suggests that either behavioural and physiological effects were not stronger enough to lead to fitness costs, or that they were in fact adaptive responses to artificial light. Alternatively, light pollution could lead to non-random settlement patterns, so that only birds with specific traits are able to breed under bright night lights. Further research should focus on distinguishing between these different options to fully elucidate the long-term implications of light pollution for wild populations.

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S5-2 Donatelli, CM*; Roberts, AS; Baxter, D; Abu-Badr, L; Naughton, L; Han, L; Ortiz, F; Standen, EM; University of Ottawa, University of California Davis, Tufts University, The College of William and Mary, Bucknell University, Denison University; *cassandra.donatelli@gmail.com*

Fabulous fish tails: Using morphology to model functional diversity across the fish tree

When we think of fish tails, we usually think of the caudal fin. But, the "tail" of a fish is much more than just the last bit. Like a cat, the tail starts just behind the vent and includes all the vertebrae, muscle, skin, and spines from that point to the tip of the fin. At some point in their lives, most fishes use their tail for locomotion. Even pectoral fin swimmers like poachers (Agonidae) and surfperch (Embiotocidae) use their tails for quick movements. Despite their seemingly similar function in propulsion, the morphology of fish tails is extremely diverse from the internal structure of the vertebrae to the external shape and composition of the skin. All fish tails have the same base components. We can model how the shapes of these components result in different material properties and swimming kinematics, in order to answer broad questions about tail evolution and function. We started by measuring the 2D vertebral morphology of the tails of 80 species of fish. We then created a model to translate how the 2D shape of the intervertebral material relates to the 3D structure. To develop an understanding of the mechanics, we measured bending stiffness of whole fish tails, tails with components removed (skin, muscle, etc), and isolated vertebral joints. Finally, we measured the swimming kinematics of 20 species of fishes. Using these data, we created a model showing how the different shapes of the tail vertebrae across the fish tree leads to the diversity of tail function in fishes. This model can be applied to fishes not used in this study to address questions of function throughout evolutionary history.

101-2 Douglas, HD; Grambling State University; *hddouglas@gmail.com*
Observations of ecological discordance at Bering Strait during a marine heat wave
Global climate change is increasing variances in natural system, and this was also evident in northern Bering Sea during a marine heat wave that intensified in 2016. Crested auklets (Aethia cristatella), colonial seabirds of Alaska and Siberia, nest at mega-colonies (10^6) in the northern Bering Sea. The usual patterns of phenology and foraging were disrupted in 2016. Colony attendance of crested auklets was 35-50% lower in latter June 2016 at Little Diomede I., AK, compared to 2015. The pattern was similar for the least auklet (A. pusilla). The two species nests sympatrically in

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rock talus. Crested auklets specialize on large zooplankton such as euphausiids and copepods. However, their C/N stable isotope values spanned three times the range in 2016 compared to 2015. Red blood cells in 2015 had greater enrichment of $\delta^{13}C$ ($t_{0.05(2)86} = 11.3$, $p < 0.001$) and lower values of $\delta^{15}N$ ($t_{0.05(2)78} = 11.4$, $p < 0.001$). In 2016 crested auklets had a less specialized diet and apparently foraged at higher trophic levels. Eleven percent of the crested auklets captured in 2016 (n=82) had incomplete acquisition of bill pigment. According to a phenology study, bill pigmentation is completed by early May. The bill pigment includes a fluorochrome that may be derived from euphausiid prey, as well as pentacyclic triterpenoids, that must originate in phytoplankton. In 2016, the species-specific citrus-like odorant was less evident and ceased earlier. These deficiencies suggest physiological limitations related to diet. Like the crested auklet, least auklets exhibited a disrupted consumption pattern. Their growing primary feathers had lower $\delta^{13}C$ values ($t_{0.05(2)21} = -4.06$, $p< 0.001$) and higher $\delta^{15}N$ ($t_{0.05(2)21} = 8.22$, $p< 0.001$) in 2016. While the northern Bering Sea is highly variable, the sharp discordance in 2016 was more extreme and appears to be related to the direct or indirect effects of increased ocean heat.

16-8 Driver, RJ*; White, ND; Balakrishnan, CN; East Carolina University, National Eye Institute; *driverr16@students.ecu.edu*
Evolution of visual perception in response to dietary shift and sexual selection
How animals perceive the world varies considerably within a diverse spectrum of behaviors and environments. Over evolutionary time, survival strategies of a lineage change, necessitating sensory perception to fine tune to new niches. Manakins, a group of Neotropical birds (suboscines: Pipridae), have undergone major shifts in both diet and sexual selection complexity in a relatively short evolutionary time frame. Manakins are broadly separated into two clades separated by 16 million years of divergence. One clade is insectivorous and males exhibit rudimentary courtship displays, while another more diverse clade is primarily frugivorous and males conduct elaborate athletic courtship displays. Using full genome sequences from representatives within both clades, we investigate how genes involved in visual perception have changed with respect

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to these different lifestyles. For the opsin gene family, we find that melanopsin (OPN4M), involved in the pupil's reflex in response to light, shows positive selection in the lineage leading to all manakins. We also find that the shortwave sensitive 1 opsin (SWS1) shows positive selection in the lineage leading to frugivorous manakins with elaborate displays. SWS1 is involved in absorption of violet and ultraviolet pigment, suggesting that perception of these colors may be important for fruit detection or courtship perception. We identify sites in SWS1 experiencing positive selection, including a shift from valine to isoleucine at position 158 in frugivorous manakins, however we do not detect positive selection at any previously characterized SWS1 spectral tuning residues. We suggest that future studies investigating SWS1 wavelength absorption consider novel spectral tuning candidates and that spectral tuning sites in SWS1 may be more diverse than currently characterized.

15-4 Dror, S*; Miklósi, A; Temesi, A; Sommese, A; Fugazza, C; Department of Ethology, Eötvös Loránd University, Budapest; *shanymd@gmail.com*

"Who's a smart boy?" Qualitative variation in the ability of dogs to learning object names

Few studies describe the abilities of dogs to retrieve objects based on their names. These studies illustrate the behavior of only a single dog, raising the question of how common is this ability. Over two years we searched for such Word Knowledgeable (WK) dogs around the globe via social media and located six dogs that knew the names of over 15 objects. We compared the rate in which WK dogs learn words to that of naive puppies (N=13) and naive adult dogs (N=17). In weekly training sessions, owners were instructed to playfully interact with their dogs using two toys (one at a time) as they repeated the toys' names. They continued this training on a daily basis at home. The dogs' progress in learning the toys' names was assessed on a monthly basis, using an object choice test with the toys positioned out of the owners' view in order to control for a Clever Hans effect. After 3 months, none of the naïve dogs was able to learn the names of the two toys. In contrast, WK dogs learned not only the names of these two toys but also the names of additional 16-37 new toys. The findings suggest that the ability to

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learn object names varies qualitatively, manifesting in only a small number of exceptional individuals. During the domestication process, dogs evolved the potential for social skills that are functionally similar to those of humans, and are therefore an outstanding model for understanding cognitive processes. Dogs with exceptional word-learning skills give us a unique opportunity to study the manifestation of exceptional skills in a non-human species. The identification of this variation in a non-human species paves the way for future studies to examine the origin of variation in human socio-cognitive performance.

15-1 Dror, S*; Magyari, L; Fugazza, C; Miklósi, A; Andics, A; Department of Ethology, Eötvös Loránd University, Budapest, MTA-ELTE 'Lendület' Neuroethology of Communication Research Group, Hungarian Academy of Sciences; *shanymd@gmail.com*

Comparing the ability of miniature pigs and family dogs to learn iconic and non-iconic orientation cues

Gestures had a crucial role in the evolution of human language, therefore investigating gesture comprehension in nonhuman species is of great interest. Family dogs can spontaneously follow pointing gestures, possibly as a result of selection for cooperation skills during the domestication process. Unlike dogs, pigs were domesticated as meat stock. Previous work suggests that pigs do not spontaneously follow human gestures but can be trained to do so. This study compared the ability of similarly raised dogs (N=10) and miniature pigs (N=6), to react to iconic (IC) and non-iconic (NI) cues. We hypothesized that the difference in the domestication goals will result in dogs outperforming pigs. In addition, as owners often use IC gestures for communicating with their pets, IC cues were expected to result in higher performance. Subjects were trained to approach food dispensers positioned on their left and right based on an experimenter given cue. In each specie, half of the subjects received cues given by the experimenter's legs, and half received hand gestures as cues. Both species learned the IC and NI hand cues with higher than chance performance. However, both performed better with IC hand cues. Dogs performed better than pigs with hand given IC cues. Both species performed at chance level when receiving leg cues. we conclude that dogs are more successful in reacting to human gestures and suggest that iconicity

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facilitates learning in dogs more than in pigs. We attribute the low performance for leg cues to an attentional bias, as all subjects were used to receiving food from the experimenter's hands.

12-5 Du Clos, KT*; Gemmell, BJ; Colin, SP; Costello, JH; Dabiri, JO; Sutherland, KR; University of Oregon, University of South Florida, Roger Williams University, Providence College, California Institute of Technology; *duclos@uoregon.edu*

Synchronous swimming in siphonophores yields higher maximum speeds but lower efficiency and higher cost of transport

While not closely related taxonomically, salps and siphonophores share a "multi-jet" swimming strategy in which thrust for the colony is produced by multiple zooids, each of which produces its own jet. Jets can be reoriented for thrust vectoring and fired either asynchronously or synchronously, providing a range of possible propulsion strategies. We developed a numerical model of multi-jet swimming to test the relative advantages of multi-jet propulsion strategies while keeping other factors, such as thrust, constant. We used model runs parameterized based on high-speed videography of free-swimming siphonophores (*Namomia bijuga*) to compare asynchronous and synchronous swimming modes. Asynchronous swimming-in which nectophores (swimming zooids) jet sequentially-is a steady swimming mode, while synchronous swimming-in which nectophores jet simultaneously-is commonly used for escape swimming. For the same thrust input, synchronous swimming yields a lower propulsion efficiency, higher cost of transport, and lower mean swimming speed than asynchronous swimming. However, maximum swimming speed is higher for synchronous than for asyncronous swimming. We also tested the consequences of varying nectophore numbers. As the number of nectophores increases, asynchronous swimming produces thrust over a larger fraction of the swimming cycle, and the magnitudes of the aforementioned differences between swimming modes increase. These results demonstrate how multi-jet swimmers can vary the timing of thrust production to favor energy conservation for steady swimming or maximum swimming speed for escape swimming.

65-4 Duncan, MI*; James, NC; Potts, WM; Bates, AE; Stanford

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University, Stanford, CA, USA, South African Institute for Aquatic Biodiversity, South Africa, Rhodes University, South Africa, Memorial University, Canada; *murray04@stanford.edu*

Different drivers, common mechanism: The distribution of a reef fish is restricted by local scale oxygen and temperature limits on aerobic metabolism

The distributions of ectothermic marine organisms are limited to temperature ranges and oxygen conditions which support aerobic respiration, quantified within the Metabolic Index (MI) as the ratio of oxygen supply to metabolic oxygen demand. However, the utility of MI at local scales and across heterogeneous environments is unknown, yet these scales are often where actionable management decisions are made. Here we test if MI can delimit the entire distribution of marine organisms at local scales (10 km) using the endemic reef fish, Chrysoblephus laticeps, which is found in the highly heterogeneous temperature and oxygen environment along the South African coastal zone. In laboratory experiments we find a bi-directional (at 12 C) hypoxia tolerance response across the temperature range tested (8 to 24 C), permitting a piecewise calibration of MI. We then project this calibrated MI model through temperature and oxygen data from a high spatial resolution ocean model to quantify various magnitudes of MI across space and time paired with complementary C .laticeps occurrence points. Using random forest species distribution models, we quantify a critical MI value of 2.78 below which C. laticeps does not persist and predict current and future distributions of C. laticeps in line with already observed distribution shifts. Overall, we find that C. laticeps' distribution is limited by increasing temperatures towards its warm edge but by low oxygen availability towards its cool edge, which is captured within MI at fine scales and across heterogeneous oxygen and temperature combinations - supporting MI's application to make local-scale predictions for local management solutions.

83-3 Duong, PC*; Holmes, HL; Piermarini, PM; Romero, MF; Gillen, CM; Kenyon College, Gambier, OH, Mayo Clinic, Rochester, MN, The Ohio State University, Wooster, OH; *duong1@kenyon.edu*

Functional expression of insect Na+-dependent cation-chloride cotransporters in Sf9 cells

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Na^+-dependent cation chloride cotransporters (CCCs) couple the inward movement of Cl^- to Na^+ and/or K^+. *Aedes aegypti* expresses three putative CCCs. AeNKCC1 is the ortholog of *Drosophila* Ncc69, a bumetanide-sensitive Na^+-K^+-$2Cl^-$ cotransporter (NKCC), while aeCCC2 and aeCCC3 are orthologs of *Drosophila Ncc83*. In prior work, *Xenopus* oocytes expressing aeCCC2 exhibited increased Li^+ uptake and Na^+ currents, but equal Rb^+ uptake, compared to water-injected controls (Kalsi et al., 2019). To further investigate the transport properties of NaCCC2s, we transiently transfected Sf9 cells with aeCCC2, Ncc83, and Ncc69 subcloned into pIB/V5-His vectors. In cells transfected with pHluorin-tagged Ncc83, plasma membrane expression was confirmed by fluorescent microscopy. Transport activity was assessed by exposing cells to saline with 20 mM [Li^+] (Na^+ tracer) and 5 mM [Rb^+] (K^+ tracer) and evaluating uptake via cation chromatography of cell lysates. Na^+ to K^+ ratios of cells transfected with aeCCC2 were 1.8 - 2.0 fold greater than controls and cells transfected with Ncc69. Following hypotonic pre-incubation, cells transfected with Ncc69 had 2-3 fold greater Rb^+ uptake compared to controls. Additionally, cells transfected with aeCCC2 tended to have greater Li^+ uptake, but equal Rb^+ uptake, compared to vector-only controls. Our results support the hypothesis that, in contrast to Ncc69 and other NKCCs, aeCCC2 transports Na^+ but not K^+. (Funding: American Physiological Society Research Career Enhancement Award, NIH F33 GM131599, and Kenyon College.)

19-1 Duque, FG*; Carruth, LL; Neuroscience Institute, Georgia State University, Atlanta, GA; *fduque1@gsu.edu*

Do smaller hummingbirds sing higher pitched songs?

Song variation in birds is influenced by multiple factors, creating the great diversity of vocal signals we have today. Evidence shows that body size can constrain the vocal range of a species so that the smaller an animal is, the higher the frequency (Hz) at which it vocalizes. Some hummingbirds vocalize above 8 kHz, beyond the vocal range of most birds. However, their body mass varies (4.85 - 8.2 g), and some are large compared to hummingbirds that do not produce any known high-frequency (HF) vocalizations. Here, we investigated whether there is an inverse relationship between body mass and fundamental frequency (F_0) in the vocalizations of hummingbirds,

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including those that produce HF vocal signals. The linear regression analysis did not show a relationship between body mass (g) and the F_0 (kHz) in the vocalizations of hummingbirds. Among all hummingbird species, the average weight is 5.32 g, SD 2.3 g; but some species producing HF vocalizations weigh more than the average, while the smallest hummingbirds produce no known HF calls. An analysis of the vocal range of each species shows that variation in frequency range is not associated with weight. *Oreotrochilus chimborazo*, for example, weighs 8.2 g and produces a chasing call with F_0 = 4 kHz, while its HF song reaches F_0 = 13.4 kHz. In contrast, some of the smallest species exhibit a vocal range comparable to that of the Giant Hummingbird. These results suggest that body mass is not a key component for variation in the frequency (kHz) of vocal production in these birds. In contrast, the position and morphology of the syrinx may be more relevant for understanding the role of physical constraints in the evolution of HF vocalizations in hummingbirds.

103-3 Dutel, H*; Porro, LB; Fabre, A-C; Martin-Silverstone, E; Berks, H; Fagan, MJ; Rayfield, EJ; University of Bristol, University College London, The Natural History Museum, London, University of Hull; *h.dutel@bristol.ac.uk*

Functional evolution of the skull during the fish-tetrapod transition: insight from living vertebrates

The colonization of land during the Devonian represents a major environmental transition in the evolution of vertebrates, which had a major impact on the evolution of essential functions such as feeding. Palaeontological discoveries have shed light on the sequence of anatomical transformations leading to early land-dwelling tetrapods. However, it is still unclear how changes in skull form relate to functional evolution in sarcopterygian fish and early tetrapods. Tackling this question requires a deeper understanding of skull anatomy and function in living taxa bracketing the fish-tetrapod transition. We first measured in vivo bite force in a sample of more than 50 fish, amphibian and amniote species and found that bite force varies significantly with phylogeny and ecology (terrestrial versus aquatic). We then quantified how bite force relates to jaw morphology using geometric morphometrics and found a strong co-variation between mandibular

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shape and bite force. In addition, we are using biomechanical modelling to determine how the reorganisation of the cranial musculoskeletal anatomy across the fish-tetrapod transition led to changes in skull kinetic parameters during feeding. We develop biologically informed multibody dynamic models of 5 living species to simulate and compare muscle activity, joint-reaction forces and bite force. This deeper understanding of the anatomy and function of the skull in living taxa will allow us to reconstruct morphological and functional evolution in fossil lobe-finned fishes and early tetrapods.

95-3 Eap, D*; Correa, S; Ngo-Vu, H; Derby, CD; Georgia State University ; *deap2@student.gsu.edu*

Chemosensory basis of feeding behavior in pacific white shrimp, Litopenaeus vannamei

Chemosensory basis of feeding behavior in pacific white shrimp, *Litopenaeus vannamei* Dana Eap, Sara Correa, Hanh Ngo-Vu, and Charles D Derby Neuroscience Institute, Georgia State University, Atlanta The Pacific white shrimp, *Litopenaeus vannamei*, is important as the principal species in the worldwide aquaculture of shrimp. It has also become a model in the study of crustacean biology, especially since it is one of the first decapod crustaceans to have its genome sequenced. This study examined an aspect of the sensory biology of these shrimp that is important in their aquaculture, by describing their peripheral chemical sensors and how they are used in acquiring and consuming food pellets. We used scanning electron microscopy to describe the diversity of sensilla on the shrimp's major chemosensory organs - antennules, antennae, mouthparts, and legs. We then explored the roles that these chemosensory organs play in the shrimp's search for, acquisition, and ingestion of food pellets, using behavioral studies on animals with selective sensory ablations. We found that the antennules mediate odor-activated searching for pellets, with both the lateral and medial antennular flagella contributing to this behavior and thus demonstrating that both aesthetasc (olfactory) and distributed chemosensors on the antennules can mediate this behavior. Once the shrimp finds and grasps the food pellet, the antennular chemoreceptors no longer play a role, and now the chemoreceptors on the mouthparts and legs control ingestion

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of the pellets. This sequence of chemosensory control of feeding in L. vannamei, a dendrobranchiate crustacean with small antennules and an ability to live and feed in both benthic and pelagic environments, is generally similar to that of the better studied, large-antennuled, benthic reptantian crustaceans including spiny lobsters, clawed lobsters and crayfish, and crabs.

17-3 Eaton, KM*; Bernal, MA; Backenstose, NJC; Yule, DL; Krabbenhoft, TJ; University at Buffalo and Auburn University, University at Buffalo, US Geological Survey, Great Lakes Science Center, University at Buffalo; *kme0038@auburn.edu*
Nanopore amplicon sequencing reveals molecular convergence and local adaptation of rhodopsin in Great Lakes salmonids
Local adaptation to novel environments is an important driver of divergence among closely related species. We have examined the process of local adaptation to distinct visual environments among the cisco species flock (Coregonus spp.) of Lake Superior. We developed a new protocol for long-read amplicon sequencing using the Oxford Nanopore Flongle device, and employed this pipeline to genotype five visual opsin genes from individuals of C. artedi, C. hoyi, C. kiyi, and C. zenithicus from Lake Superior. Results revealed high levels of differentiation in a key amino acid residue involved in the spectral tuning of rhodopsin (Tyr261Phe), with the allele for 261Phe fixed in C. kiyi. This species is typically found at depths of 80 to >200m, a blue-shifted light environment as compared to the surface. The concordance between C. kiyi's preferred habitat and the predicted 8 nm blue-shift in rhodopsin's absorption spectrum associated with the 261Phe allele provides compelling evidence that this species is adapted to life in deep water. Additionally, an ancestral reconstruction of the amino acid state at rhodopsin residue 261 across the fish tree of life has shown that the changes observed in Coregonus spp. independently parallel those found in other distantly related lineages. In certain lineages, it even appears that "toggling" back and forth between the two allelic states at this site has occurred over deep evolutionary time.

109-5 Eberts, ER*; Guglielmo, CG; Welch, KC; University of Toronto

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at Scarborough, Toronto, ON, University of Western Ontario, London, ON; *erich.eberts@mail.utoronto.ca*

Ruby-throated hummingbirds (Archilochus colubris) abandon an energy emergency torpor strategy when they fatten for migration in late summer

Hummingbirds can use torpor to reduce their metabolic rates overnight as part of a strategy to manage daily energy balance or to maximize energy storage during certain life stages. However, the proximal mechanisms that trigger (or delay) torpor use, and how these vary temporally and in response to the environment, are poorly understood. While torpor may be used only when energy stores fall below a critical level, an 'emergency only' strategy may be abandoned to facilitate fat conservation during migration. We tracked body composition and torpor use in male ruby-throated hummingbirds (*Archilochus colubris*) throughout the breeding season and the beginning of the fall migration period using quantitative magnetic resonance, respirometry, and thermal imaging. During the summer, birds entered torpor at very low estimated fat stores (~5% of body mass). Interestingly, torpor use occurred repeatedly during the migratory period in birds that had accumulated high body fat stores (>25%). Additionally, hummingbirds decreased torpor duration, and increased torpor depth in the migration season. Overall, in the breeding season, leaner hummingbirds used torpor more often and longer, when their energy reserves approached a low emergency threshold. However, torpor use at high fat stores in the migratory season suggests that some individuals are also able to use torpor to facilitate storage of fat needed to fuel their migratory journey. This study explores individual variation in hummingbird torpor use to elucidate the mechanistic link between torpor use and seasonal changes in body composition.

S6-7 Echeverri, S; Miller, AE; Chen, J; McQueen, E; Plakke, M; Spicer, M; Hoke, KL; Stoddard, MC; Morehouse, NI*; University of Pittsburgh, Princeton University, Emory University, University of Kansas, University of Puget Sound, Colorado State University, University of Cincinnati; *nmorehouse@gmail.com*

How signaling geometry shapes the efficacy and evolution of animal communication systems

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Animal communication is inherently spatial. Both signal transmission and signal reception have spatial biases--involving direction, distance and position--that interact to determine signaling efficacy. For example, color signals are often visible only from specific angles, and animal eyes often have limited fields of view for color perception. Alignment between these directional biases is therefore critical for effective communication, with even slight misalignments disrupting perception of color information. Signals can also degrade as they travel from signaler to receiver, and environmental conditions that impact transmission can vary over even small spatiotemporal scales. Thus, how animals position themselves during communication is likely to be under strong selection. Despite this, our knowledge regarding the spatial arrangements of signalers and receivers during communication remains surprisingly coarse for most systems. We know even less about how signaler and receiver behaviors contribute to proper signaling alignment over time, and how signals themselves may have evolved to influence and/or respond to these aspects of animal communication. Here, we first describe why researchers should adopt a more explicitly geometric view of animal signaling, including issues of direction, distance, and position. We review how signaling geometry influences communication dynamics across signaling modalities. We then explore how recent scientific advances (e.g., new tools for monitoring animal movements) offer inroads into this important aspect of animal communication. We conclude with recommendations and future directions made visible by attention to the geometry of signaling.

37-4 Edgar, A*; Martindale, MQ; University of Florida; *allison.edgar@whitney.ufl.edu*

Reproductive maturity occurs before transition to adult morphology in the ctenophore Mnemiopsis leidyi

Ctenophores are an important model system for understanding embryonic development in early-branching metazoans, as well as an ecologically significant invasive species. Spawning during the juvenile life stage has been observed several times in lobate ctenophores but whether early reproduction is a rare, inducible phenotype or a standard life history stage has been unexplored. We found that spawning in cydippid-stage *Mnemiopsis leidyi*, the most

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commonly studied model for lobate ctenophore biology, occurs reliably given adequate nutrition. We define environmental and feeding conditions that favor reliable spawning and characterize its typical onset, duration, and fecundity. Furthermore, we show that the offspring of these juvenile parents develop normally and themselves initiate spawning at a similar developmental time, tested through the F3 generation, so that multiple sexually mature generations from the same line may be cultured simultaneously. This discovery significantly shortens the generation time for this ctenophore in the laboratory setting and may reduce the difficulty of culturing animals and obtaining embryos for researchers working inland and without advanced marine culture facilities. These results are an important step in making this ctenophore model system more accessible. Furthermore, these results suggest that the apparently juvenile cydippid stage may in fact be an adult life stage and that the transition from cydippid to lobate morphology is a purely morphological transition not related to physiological adulthood. Alternatively, if there are physiological distinctions between these reproductive life phases, it would support the hypothesis that the cydippid stage of ctenophores is the ancestral adult stage and precocious reproduction is vestigial, with lobate reproduction arising later as a novel life history stage.

104-3 Edmonds, CE*; German, RZ; Gould, FDH; Steer, KE; Adjerid, K; Bond, LE; Mayerl, CJ; Northeast Ohio Medical University, Rootstown, OH, Rowan School of Osteopathic Medicine, Stratford, NJ; *cedmonds@neomed.edu*

Capsaicin improves swallow safety during infant feeding

During infant feeding, aspiration (the introduction of liquid material into the airway) represents a performance failure with potentially serious consequences including aspiration pneumonia and even death. Recent work has indicated that the primary mechanism driving aspiration in infants is the volume of milk being swallowed, with higher volumes increasing the likelihood of aspiration. An effective means of managing bolus volume should, therefore, result in enhanced swallow performance. In healthy populations, the afferent nerve fibers associated with the interior branch of the superior laryngeal nerve (iSLN) are responsible for regulating bolus volume by triggering a swallow. In adults,

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chemical stimulation of the afferent fibers of the iSLN via capsaicin has been shown to decrease the time to swallow onset and improve swallow safety. Whether this relationship holds for infant populations remains unknown. We filmed infant pigs with unilateral iSLN lesions while bottle feeding using high-speed videofluoroscopy under two conditions: prior to capsaicin application, and directly after the application of capsaicin to the soft palate and valleculae. We found that capsaicin application impacted feeding behaviors and kinematics. Furthermore, bolus size was significantly smaller in infant pigs exposed to capsaicin, resulting in a decreased probability of aspiration. Our results indicate that capsaicin may be a powerful agent to improve swallow performance in compromised infants by stimulating the afferent fibers of the iSLN to reduce bolus volume.

22-4 Edwards, RA*; McClintock, JB; University of Alabama at Birmingham, Birmingham, AL, University of Alabama at Birmingham, Birmingham, AL ; *raven26@uab.edu*

An evaluation of ontogenetic allometry of defensive and feeding efficiency properties of skeletal components of the regular sea urchin Lytechinus variegatus

Ontogenetic allometric analyses can provide novel insights into aspects of evolution, ecology, and conservation. For example, a recent study found marine fish exhibit hyperallometric scaling of reproductive output in relation to body size. Accordingly, to sustain fish populations the largest size class of fish should be protected. The present study exploits a model sea urchin to explore allometry to evaluate skeletal defense and feeding efficiency (Aristotle's lantern). *Lytechinus variegatus* were sampled from St. Joseph Bay, Florida. A range of different sized juvenile to adult individuals were measured and then dissected into skeletal components. Skeletal defense was evaluated by examining whole-body wet mass versus primary spine density (#), length (mm), breakage-strength (N), and Mg-calcite levels (% - high mg skeletons are harder). Feeding efficiency was inferred from the relationship between whole body wet mass versus lantern dry wt and mg-calcite content. Results indicate that *L. variegatus* displays isometric scaling between body size and various elements of skeletal defense and feeding efficiency. Hyperallometric scaling is also seen

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between body size and lantern size. Intriguingly, many components of spine defense against predation displayed a non-significant, body size independent relationship indicating juveniles have invest heavily in spine defenses at a young age. Lantern mass displayed a strong hyperallometric relationship with test diameter reflecting the importance of elevating feeding efficiency with increasing age. In the broadest sense, the present study validates that allometric scaling is valuable as a tool to evaluate aspects of defense and feeding efficiency in marine invertebrates.

11-4 Edwards, PD*; Mastromonaco, G; Holmes, MM; University of Toronto Mississauga, Toronto Zoo; *phoebe.edwards@mail.utoronto.ca*
Social transmission of queen estradiol levels in eusocial naked mole-rats
For cooperative species, there can be great value in the synchronization of physiological states to coordinate group behavioral states. This is evident in naked mole-rats (*Heterocephalus glaber*), which have the most extreme form of cooperative breeding in mammals. Colonies have a single reproductive female, "the queen," supported by up to hundreds of colony "subordinates" which are all socially suppressed into a prepubescent state. Subordinates cooperate in colony maintenance, defense, and alloparental care. Prior work has reported that there may be social sharing of hormones between individuals in the colony; when the queen is pregnant, subordinates of both sexes develop enlarged nipples, and female subordinates can develop vaginal perforation, though none of these animals are reproductive themselves. We sought to document hormonal changes behind these observations by monitoring queen and colony estradiol levels during and after pregnancy using non-invasive fecal hormone measurement. We found that both queens and colony subordinates increased estradiol levels during the queen's pregnancy. We then tested whether treating a single subordinate in the colony with estradiol would induce the same effect in other colony members. The estradiol treatments raised the treated subordinate's levels into the pregnancy range, but other colony members remained unchanged. This indicates that the social influence on estradiol levels is specific to the queen. We examine queen behavior and pheromones as cues for triggering this prepartum colony-wide increase in estradiol. These

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results have implications for how cooperative breeders coordinate alloparental care, and how social cues can influence individual physiology.

111-3 Egawa, S*; Bishop, PJ; Pintore, R; Griffin, CT; Tsai, HP; Botelho, JF; Smith-Paredes, D; Kuratani, S; Norell, MA; Nesbitt, SJ; Hutchinson, JR; Bhullar, BAS; Yale Peabody Museum, USA; RIKEN BDR, Japan, Royal Veterinary College, UK, Virginia Tech, USA, Missouri State University, USA, Yale Peabody Museum, USA; Pontificia Universidad Católica, Chile, Yale Peabody Museum, USA, RIKEN BDR, Japan, American Museum of Natural History, USA; *shiro.egawa@riken.jp*

The evolutionary change of morphogenesis of dinosaur-type femoral head

Dinosaurian femoral heads are distinguished by considerable medial extension or overhang of the proximal end. This morphology has been central to discussions of form and function of the locomotor apparatus. Here, we reconstructed the morphogenetic (developmental) evolution of the proximal end of the dinosaurian femur. Embryology of extant close relatives (neontology) suggests acquisition by gradual medial growth of the proximal end. On the other hand, the fossil record (paleontology) suggests acquisition by torsion of the proximal end about the long axis. We resolve this apparent conflict by showing that medial overhang of the dinosaur femoral head was initially acquired by torsion, which was then superseded by growth of the medial region. Subtle anatomical shifts support this hypothesis; and their biomechanical implications and phylogenetic timing are congruent with the general consensus regarding broader morphofunctional evolution on the avian stem.

61-11 El-Shesheny, IA; Matoo, OB; DeLong, JP; Montooth, KL*; Faculty of Agriculture, Tanta University, Egypt, School of Biological Sciences, University of Nebraska-Lincoln; *kmontooth2@unl.edu*

Shifts in the thermal performance curve across molecular, individual and population levels

The thermal performance curve (TPC) provides a mathematical and physiological framework for predicting how shifts in temperature

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are expected to impact population persistence in the face of global climate change. Yet, we lack knowledge of the mechanisms that translate thermal performance of molecular, cellular and individual level traits to population dynamics. Here we fit TPCs for population growth rate, estimated using life-table analyses, and for its underlying life-history and physiological components, including female fecundity, development rate, survivorship, metabolic rate and mitochondrial function using an outbred population of the fruit fly *Drosophila melanogaster*. We find that the activation energy estimated from TPCs increases from the molecular to the population level. Flies develop rapidly at higher temperatures, but this trades off with survivorship and fecundity, generating a TPC for population growth rate that is relatively narrow and sits in between the TPCs for female fecundity and development rate. The rich data gathered for insect life-table analyses reveal a thermal-dependent maternal age effect on offspring survivorship; when developed at intermediate temperatures, females can maintain fecundity and higher offspring survivorship across a larger fraction of their lifespan. We will present preliminary results on how TPCs across levels respond to thermal lab evolution. We will discuss how our research may provide a predictive framework for forecasting the dynamic responses to environmental change from thermal metabolic responses through a series of currently unknown nested functions up to population level responses.

85-7 El-Shesheny, IA*; Matoo , OB; O'Brien, K; Meiklejohn, CD; Montooth, KL; University of Nebraska-Lincoln, USA and Tanta University, Egypt, University of Nebraska-Lincoln, Ohio State University; *i.elshesheny@yahoo.com*

Gene-environment interactions shape transcriptomic and organismal responses to combined ethanol and temperature environments in the fruit fly Drosophila melanogaster

Organisms acclimate and adapt to complex environments in which multiple abiotic stressors may interact with genetic variation to determine the degree of stress experienced by individuals. The fruit fly *Drosophila melanogaster* encounters ethanol during development and shows latitudinal patterns of ethanol tolerance. The expansion of *D. melanogaster* into temperate latitudes that

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experience cooler and more variable environments is coincident with the evolution of a much higher ethanol tolerance that is considered to be adaptive. We characterized variation in whole-transcriptome responses of multiple *D. melanogaster* wild-type genetic strains from temperate latitudes to larval ethanol exposure (0 or 6%) at two temperatures (16 C and 25 C) by RNA-sequencing. We identified genes that exhibited genotype-by-environment (GxE), ExE and GxExE interactions. We found that diverse pathways and co-regulated networks of genes including lipid and phospholipid metabolism, drug metabolism, autophagy, and mitochondrial function responded to developmental ethanol and temperature exposure, and that some of the transcriptional responses were via the indirect effects of ethanol to delay development and generate cellular stress in certain genetic strains. Ethanol exposure appeared to cause oxidative stress through dysregulation of fatty acid metabolism, increased production of free radicals, and downregulation of scavengers of reactive oxygen species. Finally, we will synthesize these data on gene-expression plasticity with the plasticity that we have observed in the developmental and ethanol tolerance phenotypes of *D. melanogaster* larvae under the same environmental conditions.

22-11 Elcock, JN*; Hall, KC; Donatelli, C; Farina, S; Summers, AP; University of Washington/Howard University, University of Washington, University of Ottawa, Howard University; *jaidaelcock@gmail.com*

Microstructures and measured morphometrics of skate egg cases

Skates are a speciouse group of flattened cartilaginous fishes. They are oviparous, depositing their embryos in cases that rest on the ocean floor for extended periods of time. Few nursery sites have been identified in the North Pacific, with ongoing efforts to find more for species conservation. Understanding how egg cases interact with their environment may provide insight regarding preferred nursery locations. Our goal was to determine how the overall shape of the cases and the microstructure of the external surface influences how they interact with water flow. Using a water tunnel and arduino tilt table we assessed the limits of what currents and friction eight species of egg cases can withstand before detaching from substrate. We then used scanning electron

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microscopy to examine different microstructures covering the surface of each case and analysed how egg case morphology varies between the species, measuring all portions of the cases. We did this to determine which morphometrics drive morphological diversity between species and suggest which structures may help egg cases resist detachment from substrate. Friction and flow speed did not significantly differ by orientation across species, but orientations did differ within species. We attribute this to differences in microstructures. Both friction and flow speed are dependent on species and individual, suggesting some species are better able to handle stronger flow and friction conditions than others. By understanding how species-specific microstructures and morphologies interact in a simulated environment, we can determine suitable habitats for nurseries for certain species. These new variables can be incorporated into past models to create fine scale maps of prospective skate nursery habitats.

64-5 Eleftheriou, A*; Kuenzi, AJ; Luis, AD; University of Montana, Missoula, Montana Tech of the University of Montana, Butte; *andreas.eleftheriou@umontana.edu*

Heterospecific competitors and seasonality can affect host physiology and behavior, key determinants of disease transmission

Ecological and environmental factors can influence infectious disease transmission via host physiology and behavior. Using the North American deermouse (*Peromyscus maniculatus*), the primary host for the directly-transmitted Sin Nombre hantavirus (SNV), we investigated how heterospecific competitors and seasonality affect host susceptibility to infection and intraspecific contact rates, key mechanisms of transmission. In grasslands of western Montana, deermice compete with voles (*Microtus* spp.) and shrews (*Sorex* spp.). We hypothesized that dominant voles, and less so shrews, will induce chronic stress, suppress immunity, and may change deermouse contact rates, and during spring/summer, deermice may experience chronic stress, suppressed immunity, and higher contact rates. We trapped small mammals, collected feces and blood from deermice, and evaluated them for scar numbers and body condition scores (BCSs). We evaluated stress physiology with fecal corticosterone metabolites (FCMs), neutrophil/lymphocyte (N/L) ratios and BCSs, immunity with total white blood cell (WBC) counts,

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and contact rates with scar numbers. We found that shrew density negatively correlated with stress response FCMs, and although complex interactions existed, shrew and vole densities negatively correlated with BCSs but differentially with scar numbers. N/L ratios were higher in spring/summer whereas WBC counts were lower in summer, indicative of chronic stress and immunosuppression, respectively. Our results suggest that heterospecific competitors could differentially influence disease transmission, and that chronic stress, immunosuppression, and higher contact rates may help explain higher SNV transmission previously reported in Montana during spring/summer .

BSP-10-2 Elhamod, M*; Maruf, MA; Mandke , PK; Karpatne, A; Virginia Tech; *elhamod@vt.edu*

Biology-guided neural network for species classification

In this project, we consider the problem of fish species classification where, given an external image of a fish specimen, our goal is to identify the species class of using machine learning (ML) methods. Fish species classification is an important task that is the foundation of many industrial, commercial, ecological, and scientific applications involving the study of fish distributions, dynamics, and evolution. While conventional approaches for this task have used off-the-shelf ML methods such as Convolutional neural network (CNN) architectures, there is an opportunity to inform the CNN architecture using our knowledge of biological hierarchies among taxonomic classes. In this work, we propose infusing some metadata in the form of phylogenetic information into the model's training. Namely, in a mix of supervised and unsupervised multi-task learning formulations, we use the genus of the fish to guide the structure of our model's hidden layers and relationships among the extracted features. The proposed model, named Hierarchy-Guided Neural Network (HGNN), outperforms conventional CNN models in terms of classification accuracy even with scarce training data in our extensive experimental analyses. We also observe that HGNN shows better resilience to adversarial occlusions, where some of the most informative patch regions of the image are intentionally blocked and their effect on classification accuracy is studied. Additionally, we examine HGNN from several other angles including the interpretability of the extracted

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features (using saliency map visualizations in the input image space) and the mapping of extracted features to biological traits, the diversity of these features, and the model's ability to generalize beyond seen species, over a large database of more than 23,000 images that we have recently gathered from several museums.

110-9 Eliason, CM*; Riede, T; Laverde-R, O; Goller, F; Clarke, JA; Field Museum of Natural History, Midwestern University, Pontificia Universidad Javeriana, University of Utah, University of Texas Austin; *celiason@fieldmuseum.org*

Shared acoustic allometry in the largest and smallest known birds

With parallels to human speech, rampant diversity within and among species, and a potential role in speciation, acoustic phenotypes in birds have received considerable attention since the 1950s when the spectrograph unlocked our ability to quantify acoustic variation. Studying the relative roles of innovations in and potential constraints on sound production is critical for understanding evolutionary trends in acoustic phenotypes. Most bird vocalizations are produced by vibration of vocal folds within the syrinx, a novel organ to birds located near the juncture between the trachea and bronchi. Morphological structures like the syrinx are expected to scale together as an organism grows, therefore selection on body size might influence the evolution of other size-linked traits. Several studies have demonstrated allometric scaling of fundamental frequency (F0) in avian sub-clades-including songbirds and tinamous. However, there have been no studies looking at the evolution of acoustic allometry across birds. Studying how acoustic allometry evolves is critical for understanding whether sub-clade acoustic allometries reflect overall clade trends and reconstructing sounds made by extinct non-avian dinosaurs. Here, we build a synthetic dataset of body size and F0 in birds and utilize a suite of comparative methods to test the hypothesis that acoustic allometries are shared across birds. We also generate new data for three clades spanning the extremes of body sizes in birds to understand how well we can predict acoustic traits from body size. Our results have implications for reconstructing the sounds of extinct animals and elucidate how innovations and constraints shape acoustic diversity across birds.

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51-10 Ellepola, G*; Pie, MR; Meegaskumbura, M; Eco-Evo-Devo Group, Guangxi Key Laboratory for Forest Ecology and Conservation, College of Forestry, Guangxi University, China, Departamento de Zoologia, Universidade Federal do Paraná, Brazil; *gajaba3@gmail.com*
Climatic correlates of the diversification in Old World tree frogs: cool-wet regions and islands as refuges and species pumps
With 428 described species, Old World tree frogs (rhacophorids) form a spectacular diversification spanning a climatically variable region across much of mainland Asia, nearby islands, and parts of Africa. Their diversification, particularly in relation to their climatic niche, remains poorly understood, mostly due to incomplete data and taxon sampling. Hence, we provide a complete, species-level phylogeny of all extant rhacophorids by integrating phylogenomic/Sanger sequence data and phylogenetic imputation to delineate patterns of their diversification. Lineage-Through-Time plots show a constant rate of diversification with a slight increase towards present. We determine rates of diversification and spatial variation in distribution of species and delineate spatiotemporal variation showing high species accumulation in rainforest habitats around Borneo, peninsular Malaysia, Vietnam, Yunnan (China), Western Ghats and Sri Lanka. Climatic niche and phylogeography analyses explain how spatial and temporal structuring is shaped by the evolution of their climatic niches. We highlight cool-wet regions and islands being associated with regions of high species accumulation hence contributing towards generation and maintenance of their diversity; knowledge vital for their conservation. Further, a higher disparity of climatic niche evolution is evident since Eocene-Oligocene transition - species in East/Southeast Asia, Himalaya evolved towards colder climatic conditions while species inhabiting Sundaland and Peninsular India evolved towards warmer climatic conditions.

85-8 Elmore, JW*; Stillman, JH; Dahlhoff, EP; Rank, NE; Sonoma State University, Santa Clara University, University of California, Berkeley and San Francisco State University; *elmore@sonoma.edu*
Transcriptional responses to thermal and oxygen stress in a montane leaf beetle

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Mitonuclear incompatibilities may manifest as differences in energetic output and ability to recover from exposure to stressful conditions. The strength of a mitonuclear incompatibility is influenced by exposure to physiological stress and may vary along environmental gradients. Our understanding of mechanisms underlying mitonuclear incompatibilities may be improved by examining transcriptional responses to interacting stress factors. We examined effects of reduced oxygen supply and heat stress exposure on gene expression for the montane leaf beetle *Chrysomela aeneicollis*. Beetle larvae were reared at 1500 m (low elevation) or 3090 m (natural elevation) above sea level. When they reached the third instar, we measured their performance, exposed them to a control (20C) or thermally stressful temperature (36C), and measured performance after stress. Results revealed that beetles reared at natural elevation recovered better than beetles reared at low elevation, and mitochondrial and nuclear genotypes related to stress recovery. We quantified gene expression in 96 individuals and found that both genotype and stress exposure have an effect on the relative expression levels of genes. Results will be further described in this talk.

65-7 ElShafie, SJ; University of California, Berkeley; *selshafie@berkeley.edu*

Does body size correspond to environmental temperature in reptiles over geologic time scales?

Metabolic theory predicts that maximum body size should correlate with environmental temperature in reptiles. But studies of this relationship in extant reptiles have not revealed consistent patterns among higher order taxonomic groups. Could there be a relationship between these variables over millions of years? Here, I test the hypothesis that body size range in assemblages of lizards and crocodylians correlates with transitions in environmental temperatures over geologic time intervals. I estimated snout-vent length (SVL) using regressions from extant specimens for 274 lizard and 234 crocodylian specimens from the Western Interior of North America through the Paleogene (66-23 Mya), which spans several warming and cooling events evidenced by terrestrial and marine proxies. My results indicate that maximum lizard SVL has a positive linear relationship with local

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terrestrial temperature across this geotemporal system. These results reflect some recent findings that local temperature may correlate with body mass in extant lizards. In contrast, crocodylian SVL does not track local terrestrial temperatures across this system, but does indicate a positive linear relationship with concurrent global marine temperatures. This result could reflect the aquatic habits of crocodylians, or possibly migration into the interior basins from lower latitudes. Other studies of this relationship in fossil and extant crocodylians have yielded contradictory results and suggest that body size in this group may be more associated with ecology and resource availability than with ambient temperature. While the relationship in crocodylians remains elusive, this study offers new evidence to suggest that maximum lizard body size may be constrained by terrestrial environmental temperature on both ecological and evolutionary time scales.

64-3 Emery, M*; Dimos, B; Mydlarz, L; University of Texas at Arlington ; *madison.emery@mavs.uta.edu*

The expansion and loss of pattern recognition receptors across the phylum Cnidaria

Pattern recognition receptors (PRRs) are crucial components of innate immunity, recognizing danger-associated molecular pattern motifs (DAMPs) and activating host defenses. Because invertebrates rely solely on their innate immunity to defend themselves from pathogens, the specificity of their immune systems is the consequence of their PRR repertoire. As members of a basal non-bilaterian phylum, investigating Cnidarian PRRs gives insight into the evolution of innate immunity. Previous investigations into Cnidarian PRRs have found expansions in NOD-like receptors and C-type lectins. However, these studies focus on Hexacorallians and a single Hydrozoan, Hydra, and do not reflect the full diversity of the phylum. Here we utilize the increasing amount of available genomic resources to survey the PRR repertoire of 15 Cnidarians from the classes Hexacorallia, Octocorallia, Cubozoa, Hydrozoa, Scyphozoa, and Staurozoa. Similar to previous studies, we found expansions in NOD-like receptors and C-type lectins in the majority of species. Interestingly, no NOD-like receptors were found in the Staurozoan's and Cubozoan's predicted gene models. RIG-like

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receptors and Toll-like receptors were either conserved or lost in the majority of species surveyed. Interestingly, Anthozoans (Hexacorallia, Octocorallia) consistently had higher numbers of PRRs across all four PRR types relative to Medusozoans (Cubozoa, Hydrozoam Scyphozoa, and Staurozoa). However, this pattern does not appear to extend to downstream signaling pathway completeness, as the majority of Cnidarians surveyed have similar levels of completeness in the pathways leading from the PRRs to immune regulator NFκB and the complement system.

84-4 Enns, JL*; Purdey, L; Stojkovic, L; Williams, TD; Simon Fraser University; *joannae@sfu.ca*

Sex and strife: parental cooperation in a songbird species with flexible biparental care

Sexual conflict occurs in socially biparental species because working together provides shared benefits while incurring individual costs. In birds, coordination of nest visits (or turn-taking) during chick provisioning has been suggested as a strategy to mitigate this conflict. This alternation of visits requires that birds have access to information on their partner's behaviour, allowing pairs to respond to each other "in real time". To date, evidence in support of this has come from species that likely have direct information on their partners, i.e., close foraging distances or synchronized feeding visits. Further, there has been little discussion in regards to ecological context - how annual variation, brood type, and paternal effort might affect coordination. Here we describe parental behaviour during chick rearing in the European starling, *Sturnus vulgaris*, where direct access to information is unlikely and there is marked variation in the amount of paternal care that each nest receives. We analyzed provisioning visit times over 4 consecutive years, for first and second broods along a continuum of brood sizes and chick ages, to determine how parental behaviour varies with ecological context. Using inter-visit interval as our focal measure, we also tested the hypothesis that parents adjust their interval length, or return time, based on knowledge of their partner's feeding behaviour. Our data show that females adjust their visit times in response to their partner while males do not, in what we deem to be "asymmetric

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coordination". We will present preliminary results from a direct test of this hypothesis using a mate removal experiment.

95-7 Enriquez, MS*; Swanson, N; McGaugh, SE; Gluesenkamp, A; Mensinger, AF; University of Minnesota, Duluth, University of Minnesota, San Antonio Zoo; *enriq074@d.umn.edu*

Auditory threshold differences in recently diverged cave populations of the Mexican tetra Astyanax mexicanus

The Mexican tetra *Astyanax mexicanus* –with a native range from central/southern Mexico reaching up to the lower Rio Grande and Nueces rivers–inhabits both cave and surface environments. Life in these contrasting habitats has influenced developmental morphology, allowing for two primary morphologies to exist: cave fish and surface fish that diverged 0.2 to 1 million years ago. Cave fish are characterized by troglomorphic phenotypes: vestigial eyes, reduced pigmentation, and increased olfactory and lateral line sensitivity. Previous research indicated differences in hearing thresholds between cave and surface populations. Surface *A. mexicanus* were introduced to the San Antonio River, Texas, in the early 1900s, and subsequently colonized subterranean habitats in the Edwards Aquifer. These populations display evidence of divergence and rapid phenotypic and behavioral evolution, allowing observation on how sensory systems adapt to new environments in real time. Two surface and three cave fish populations were tested and compared for auditory sensitivity to sound pressure and particle acceleration, with both ecotypes responding to 4 kHz sound frequencies. Sound pressure thresholds between cave and surface populations differed significantly at one frequency (0.5 kHz), with significant particle acceleration threshold differences between 0.4 and 0.5 kHz and above 1.5 kHz. We hypothesize that the differences in frequency sensitivity may be due to different soundscapes between the cave and surface environments.

42-6 Ensminger, DC*; Crocker, DE; Lam, EK; Allen, KN; Vázquez-Medina, JP; UC Berkeley, Sonoma State University; *dls_david@yahoo.com*

Acute and chronic HPA axis stimulation alters white blood cell

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ratios but not inflammatory markers or oxidative stress in elephant seals

Activation of the hypothalamic-pituitary-adrenal (HPA) axis regulates immune and inflammatory responses through modulation of cytokines, white blood cells (WBCs), and oxidative stress. However, little is known about the impact of HPA axis activation during extreme physiological conditions in marine mammals. We challenged 18 post-weaning (simultaneously fasting and developing) northern elephant seal pups with daily intra-muscular injections of adrenocorticotropin (ACTH), a glucocorticoid receptor (GR) antagonist (RU486), or a combination (ACTH+RU486) for four days. Animals were blood sampled at baseline, 2 hours (2h), and 4 days (4d) after the beginning of the treatment. ACTH and ACTH+RU486 elevated aldosterone and cortisol at 2h, with the effect diminishing at 4d. RU486 alone induced a compensatory increase in aldosterone, but not cortisol, at 4d. ACTH decreased neutrophils (N) at 2h while decreasing lymphocytes (L) and increasing N:L ratio at 4d. These effects were abolished by RU486. Despite alterations in WBCs, there was no effect of ACTH on TGF-b or IL6; however, both cytokines decreased across the fast (4d). Similarly, ACTH did not impact protein oxidation, lipid peroxidation, or antioxidant enzyme activities, but lipid peroxidation and catalase decreased while glutathione peroxidase increased with fasting progression. These data show that HPA axis activation has differential acute (2h) and chronic (4d) modulatory effects on WBCs and that the chronic effect is mediated, at least in part, by GR signaling. These results also underscore the robustness and tolerance of these elephant seals to repeated HPA activation.

19-6 Erdmann, JA; Oklahoma State University; *muddynaturalist@gmail.com*

Frogtalkers: Automating the parameterization of frog calls for comparative studies

Despite huge variation in the biology of frogs (Anura), males reliably exhibit a characteristic call during breeding to attract females. Other vertebrate taxa with similar breadth in vocalization (i.e., birds and mammals) have evolved such complex acoustic signals that parameterization into discrete, inclusive features is largely precluded. The absence of this hurdle in frogs provides an

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excellent opportunity for comparative studies in call evolution. Here I explore the extent to which frogs calls in the family Hylidae can be inclusively and informatively tabulated (like features such as dominant frequency and pulse structure) automatically using machine learning techniques for the purposes of downstream comparative phylogenetic analyses.

87-3 Erickson, KL*; Quattrini , AM; McFadden, CS; Harvey Mudd College, Claremont, CA, Smithsonian Institution, Washington, DC; *kerickson@hmc.edu*

Evaluating the use of ultraconserved elements to determine species boundaries and population structure in the octocoral genus Alcyonium

Species boundaries and population structure within the anthozoan sub-class Octocorallia have been obfuscated due to insufficient differences in the morphological characters and molecular markers traditionally used to distinguish between closely related taxa. NGS methods provide unprecedented genomic resources that show promise in resolving octocoral taxonomies. Target enrichment of Ultraconserved Elements (UCEs) has been successful at resolving deep phylogenetic relationships within Octocorallia. To evaluate the utility of UCEs in resolving species boundaries and identifying admixture among octocoral populations, UCEs were sequenced from 64 Mediterranean and North Atlantic octocorals in the genus *Alcyonium*. The species boundaries among these octocorals have been corroborated across studies that used morphological, reproductive and genetic markers. 32 of these individuals represented four geographically distinct populations of the species A. coralloides. Using 2,921 recovered UCE loci, we built a highly-supported phylogenetic tree that largely resolved monophyletic clades for the putative *Alcyonium* species and *A. coralloides* populations. Within each of three clades, single nucleotide polymorphisms (SNPs) were called and used to perform Discriminant Analysis of Principal Components (DAPC) and STRUCTURE analyses. The DAPC and STRUCTURE analyses designated species that were congruent with putative species boundaries and separated *A. coralloides* individuals into populations. These analyses support that UCEs show promise as markers to resolve not only deep, but also shallow-level relationships among octocorals.

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74-6 Erickson, E*; Diaz, K; Carruthers, A; Ozkan-Aydin, Y; Chong, B; Goldman, DI; Georgia Tech; *eerickson31@gatech.edu*
Centipede locomotion on bumpy terrain
Multi-limbed invertebrates such as centipedes negotiate diverse environments via propagation of coordinated travelling waves of body and limb flexion. While progress has been made studying how these animals locomote on flat terrain, less is known about how these animals navigate and traverse more complex terrains. To study the body-limb coordination of centipedes in complex terrains, we challenged *Scolopendra polymorpha* (N=4, L = 7.7±1.5 cm, 19 joints and leg pairs) to transverse a flat surface and a Gaussian-distributed rough terrain (12 x 24 cm^2 with variable height of blocks ranging from 0 to 1.5 cm). On the flat surface, centipedes moved by generating a traveling wave along their limbs and bodies, maintaining a constant phase shift between these two waves and speeds of 0.64±0.03 body lengths per second (BL/s). On rough terrain, the centipedes moved at speeds of 0.43±0.01 BL/s and the generated traveling wave was minimally perturbed. When centipedes traversed blocks of different heights, not all limbs contacted the substrate. Instead, some limbs passively glided against the blocks, due to inherent flexibility. To test the hypothesis that centipedes can negotiate obstacle-rich environment without adjusting body-limb coordination, we developed a 70 cm long centipede robophysical model [Ozkan Aydin, Robosoft 2020] with directionally compliant limbs. The robot was able to traverse a scaled rough terrain without any sensing or control. The flexibility of the limbs allowed the robot to negotiate obstacles and avoid jamming between blocks.

93-9 Ernst, DA*; Westerman, EL; University of Arkansas; *ernstdavida@gmail.com*
Investigating sensory system variation in the developing butterfly: A molecular approach
Behavior relies on the capacity to extract and process information from the environment. Visual and chemical cues in particular are vital to survival and reproduction, mediating predator avoidance, foraging, communication, and mate choice behaviors in animals.

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Nevertheless, sensory systems often show ontogenetic shifts in structure and function, especially in animals that exhibit indirect development. To investigate developmental differences in sensory transduction and processing at the molecular level, we examined the expression profiles of genes linked to vision and chemosensation in two life stages of an insect that undergoes a dramatic metamorphosis, the butterfly *Bicyclus anynana*. Specifically, we reared animals under identical conditions and compared gene expression in the heads of late fifth instar larvae and newly-eclosed adults. Over half of all expressed genes showed significantly altered expression between the two developmental phenotypes, with 4,046 and 4,402 genes upregulated in larval and adult heads, respectively. Vision-related genes upregulated in adults were heavily biased toward phototransduction, while those upregulated in larvae were mainly associated with eye development. Additionally, the vast majority of chemosensory genes were differentially expressed between larvae and adults, several of which were homologous to lepidopteran genes associated with pheromone detection, host plant recognition, and foraging. These results reveal promising candidate genes for furthering our understanding of the sensory ecology and behavior of the disparate developmental stages of butterflies and provide insights for other animals that undergo metamorphosis.

62-14 Ershova, NA; University of Chicago; *nershova@uchicago.edu*
Diversity and prevalence of trematode parasites in the common periwinkle on the coast of Massachusetts
Parasites significantly influence the genetics of a host population, cause changes in behavior and lead to changes in host physiology and morphology. By altering the ecology of hosts, parasites shape the interactions within and the maintenance of entire communities. Trematodes are widespread and have significant implications for hosts in marine nearshore communities. Using this ubiquitous yet poorly understood group of parasites, I investigate how host-parasite interactions scale up to community dynamics. Parasites can mediate the success of an invading species which have escaped parasites or competitors in their native range. *Littorina littorea* is a snail native to Northern Europe which invaded the East Coast of North America within the last 200 years. It has since

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become the dominant snail in intertidal habitats, displacing native. I found that there are two morphologically distinct trematode species infecting this host in the Cape Cod area: *Cryptocotyle lingua* and *Cercaria parvicaudata*. While *C. lingua* has been described as the most common and abundant trematode infecting *L. littorea* in North America, I found that a second parasite species, *C. parvicaudata*, predominates in the Cape Cod region. Because trematodes that infect snails have been shown to have cryptic diversity, I am developing novel molecular methods using the reconstruction of the full mitochondrion genome to investigate the diversity of trematode parasites in *Littorina littorea*. Preliminary results suggest that *Cercaria parvicaudata* may be *Renicola roscovita*, a previously described species from other locations. Future analysis of mitochondrial DNA will allow to determine the population structure of the trematode parasites, as well as design species specific DNA probes that allow for a more effective identification and examining of trematodes at different stages of the life cycle.

47-7 Evans, AR*; Pollock, TI; Cleuren, SGC; Parker, WMG; Richards, HL; Garland, KLS; Wilson, TE; Hocking, DP; Adams, JW; Monash University, Melbourne, Australia; *arevans@fastmail.fm*

A universal power law for the growth and form of teeth, claws, horns, thorns, beaks, and shells

Universal models of biological growth and form are rare. One such model is the logarithmic spiral, which has been purported to explain the growth of biological structures such as teeth, claws, horns, and beaks. However, the logarithmic spiral only describes the path of the structure through space, and cannot generate these shapes. Here we show a new universal model based on a power law that explains the extreme diversity of tooth shapes in vertebrates, including humans, mammoths, saber-toothed cats, tyrannosaurs and giant megalodon sharks. This power cascade model can be used to predict the age of mammals with ever-growing teeth, including elephants and rodents, and determine sex in elephants. We view this as the third general model of tooth development, along with the patterning cascade model for cusp number and spacing, and the inhibitory cascade model that predicts relative tooth size. Beyond the dentition, this new model also explains the growth of claws,

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horns, antlers and beaks of vertebrates, as well as the fangs and shells of invertebrates, and thorns and prickles of plants. This model operates independently of the logarithmic spiral, and is present throughout these diverse biological systems. The power cascade provides a mechanistic basis for the generation of these pointed structures across the tree of life.

23-2 Evans, AJ*; Cohen, KE; Summers, AP; Kolmann, MA; Egan, JP; Hernandez, LP; The George Washington University, University of Washington, University of Michigan, Western Michigan University; *allysonevans@gwu.edu*

That'snot how it works: Particle aggregation in the viscous environment of the epibranchial organ

The ability to efficiently consume many small prey items involves adaptations for aggregating food particles prior to swallowing. Many teleost fishes, including clupeiforms, have an epibranchial organ (EBO) in the posterior pharynx for concentrating food captured by the gill rakers. Morphologically diverse and widely distributed among teleosts, EBOs nevertheless share some anatomical features that may be essential for particle aggregation. We describe the anatomy in a functional context by modelling fluid flow and particle aggregation in the EBO of the gizzard shad, *Dorosoma cepedianum*. Results from morphological surveys and physical modelling suggest that proper aggregation and expulsion of food can be described by transitions between inertial and viscous flow. The EBO serves as a fluid 'spreader' that takes an inertial input and rapidly decreases velocity and size scale to increase the effects of viscosity. The viscous environment of the EBO, created in part by abundant mucus, allows large numbers of particles to aggregate into a bolus. Thick walls of circumferential and longitudinal skeletal muscle enable rapid compression of the EBO which increases fluid speed and pushes the bolus into the esophagus. We propose that the input particle flow is an inertially dominated regimen, while the internal EBO flow is viscously dominated. It is possible that the output flow during bolus ejection is also inertially dominated. This conceptual model offers a framework for understanding the breadth of EBO diversity in clupeiform fishes. The variety of EBO morphologies could be related

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to differences in prey size, prey mobility, frequency of bolus formation, or density of encountered prey items.

40-4 Evans, KM*; Watson, S; Friedman, M; Rice University, New Mexico Tech University, University of Michigan; *Kory.Evans@rice.edu*

Turbot boosted: rapid and mosaic patterns of shape evolution in the flatfish skull

Mosaic evolution occurs when there are differential rates of evolution across different organismal traits. Flatfishes (Pleuronectiformes: Teleostei) exhibit striking cranial asymmetry that results from the migration of one of their eyes to the opposite side of their head during development. The developmental sequence of orbital migration has also been found to recapitulate the evolutionary transition towards asymmetry in the fossil record. However, the evolutionary tempo and mode of this orbital migration has yet to be examined in a rigorous quantitative phylogenetic comparative framework. Here we use three-dimensional geometric morphometrics and a phylogenetic comparative toolkit to examine evolutionary patterns of shape variation across 92 species of flatfishes and their relatives, and compare rates of shape evolution between different regions of the skull. We find that flatfishes on average, exhibit a 14-fold increase in their rates of skull shape evolution relative to non-flatfishes. We also find mosaic patterns of shape evolution across the skull, with the orbital and frontal regions evolving more quickly than the dorsal elements of the braincase. Interestingly, we recover rapid rates of shape evolution in the basicranium, and reduced rates of shape evolution in the most anterior regions of the skull (e.g. ethmoid region). We hypothesize that the orbital migration (localized to middle portion the skull) of flatfishes, is responsible for driving the mosaic patterns of shape evolution observed in this clade of fishes.

PLEN-1 Extavour, CG; Harvard University; *jjsocha@vt.edu*

From soma to germ line: birth, growth and transformation of a novel gene

TBD

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42-8 Fabela, RF*; May, MA; Todgham, AE; Tomanek, L; California Polytechnic State University, San Luis Obispo, Florida Gulf Coast University, University of California, Davis; *rfabela@calpoly.edu*

Response of Mytilus californianus ciliary activity to food and temperature acclimation and sirtuin inhibition

The California mussel (*Mytilus californianus*) is ecologically important in the intertidal zone and an understanding of their responses to stress may help predict how populations respond to environmental perturbation. Assimilating food into cellular energy is necessary to support a physiological stress response and studies show that previous diet may be vital for mussels responding to stressors, such as acute heat shock. Furthermore, our lab has shown that sirtuins (protein deacylases) also affect thermal tolerance in mussels and may be a link between diet and thermal sensitivity. Mussel's gills are integral for feeding and gill activity is often used to assess overall metabolic status. As such, we evaluated changes in ciliary beat frequency (CBF) in *M. californianus* following an acute heat shock and sirtuin inhibition in mussels acclimated in tidal simulators to 20° C or 30° C aerial temperatures during low tide and a low or high food ration. CBFs were video recorded on excised gill segments during high tide periods 48 h before and after heat shock on a temperature-controlled slide (10X). Mean CBF from video was determined using Cilia Beat Analyzer package (Matlab). We found CBF decreased after an acute heat shock and further decreased if mussels were also exposed to sirtuin inhibitors. There was a significant 3-way interaction between food ration, acclimation temperature, and sirtuin inhibition. This suggests a complex relationship between thermal history and food ration on the ability of mussels to respond to thermal stress and a potential role of sirtuins as metabolic stress regulators.

94-1 Fabian, ST*; Zhou, R; Lin, HT; Dept. of Bioengineering, Imperial College, London; *s.fabian@imperial.ac.uk*

Dragon-drop: The passive mechanism and active control of the dragonfly's aerial righting behaviour

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Dragonflies (Anisoptera) are capable of extreme performance and demonstrate this in predatory and conspecific interactions on a daily basis. We might presume that the manoeuvrability required for such feats would inherent instability necessary for rapid, active control. To test the ability of dragonflies to react to an undesirable flight state, we dropped common darter dragonflies (*Sympetrum striolatum*) from a range of orientations and used precise micro motion-capture technology to measure the movements of their head, thorax and abdomen as they regained a normal flight-attitude. We conducted inverted drops in darkness, demonstrating that dragonflies are still capable of righting without visual input. By dropping anaesthetised dragonflies, we found that dragonflies passively enter a stable dive but must react to regain a suitable pitch. Pitch control was managed in collaboration with movement of the abdomen relative to the thorax. We isolated distinct righting behaviours across the different conditions that formed the basis of active righting, the use of which differentiated the animal's righting reflex from purely passive stability. We concluded that the wing posture gives dragonflies a level of passive flight stability which may simplify some complex aerial tasks. Finally, mechanosensation alone is sufficient to maintain all the basic flight control while vision enables tasks specific control and adds robustness.

72-7 Fahn-Lai, P*; Regnault, S; Biewener, AA; Pierce, SE; Harvard University, Harvard University and University of Surrey; *philsometimes@gmail.com*

Ex vivo 3D measurements of shoulder mobility and muscle moment arms in sprawling and upright amniotes

The evolution of upright posture allowed synapsids and their mammalian descendants to exapt their appendicular skeletons for diverse functions and ecologies. However, the lack of skeletal correlates for posture has made it very difficult to pinpoint exactly when the transition from "sprawling" to "upright" limb posture occurred. Reconstructed muscle moment arms (MMAs) are commonly used for inferring function in extinct animals, but in order to use this approach to interpret the synapsid fossil record, we must first understand how joint range of motion (ROM) and muscle geometry interact to produce integrated function in three

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dimensions (3D)—something that has not been extensively studied in non-human amniotes. Here, we harnessed the power of X-ray Reconstruction of Moving Morphology (XROMM), the DeepLabCut machine learning toolkit, and a novel Maya-Python moment arm tool to create a comprehensive map of shoulder ROM and pose-varying MMAs in a functional and phylogenetic bracket for the synapsid stem: the sprawling Argentine black and white tegu and the upright Virginia opossum. We present a comparison between the two taxa, and illustrate the potential of this hybrid approach to overcome historical hurdles in the acquisition and analysis of densely-sampled 3D limb kinematics datasets. Future work will leverage these data to constrain and validate musculoskeletal models spanning synapsid evolutionary history to flesh out the story of mammalian postural evolution.

56-11 Fan, XZ*; Swartz, S; Breuer, K; Center for Fluid Mechanics, School of Engineering, Brown University, Department of Ecology and Evolutionary Biology and Center for Fluid Mechanics, School of Engineering, Brown University, Center for Fluid Mechanics, School of Engineering and Department of Ecology and Evolutionary Biology, Brown University; *xzfan@brown.edu*

Power requirements for flapping flight with heavy and highly articulated wings

Bats fly with highly articulated and relatively heavy wings. To understand power requirements, we have developed a three-dimensional reduced-order numerical model, and have analyzed flights of *Cynopterus brachyotis*, the lesser-nosed dog-faced bat. Using previously-measured wing kinematics, the model computes aerodynamic forces using quasi-steady Blade Element Momentum Theory and incorporates inertial forces of the flapping wing using the measured mass distribution in the wing and body. The two are combined into a Lagrangian equation of motion to predict the free flight of the animal which is compared with the experimentally observed behavior over a range of flight speeds (3.25 - 7.4m/s). To validate the model, the computed lift and thrust are compared with the forces needed to generate the observed motion in the live experiments. In general, we find good agreement, although the average thrust is slightly underpredicted. We use Monte Carlo simulations to quantify uncertainties due to measurement errors and

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modelling assumptions, and find that the simulations are most sensitive to the empirical coefficients of the aerodynamic model (lift and drag functions). We use the model to analyze flight power requirements, separating the power into aerodynamic and inertial components. We find that, towards the end of downstroke, the inertia of the heavy wing can be directed towards generation of aerodynamic power, thus alleviating the required muscle power; similarly, aerodynamic forces are found to assist the inertial requirements during the upstroke.

91-3 Farhat, S*; Tanguy, A; Espinosa, EP; Guo, X; Boutet, I; Smolowitz, R; Murphy, D; Rivara, GJ; Allam, B; Stony Brook University, Stony Brook, NY, Sorbonne Université, Roscoff, France, Rutgers University, Port Norris, NJ , Roger Williams University, Bristol, RI, Cape Cod Cooperative Extension, Barnstable, MA, Cornell Cooperative Extension, Southold, NY ; *sarah.farhat@stonybrook.edu*

Genetic markers associated with hard clam resistance to QPX disease

The hard clam, Mercenaria mercenaria, is among the most economically- and ecologically-important marine species in the United States. Several Northeastern states have suffered severe losses in hard clam stocks due to a fatal disease caused by a protistan parasite called Quahog Parasite Unknown (QPX). Previous research clearly showed that the susceptibility of clams to QPX disease is a heritable trait. Here, we generated a draft genome of the clam and used ddRADSeq methods to identify SNPs associated with disease resistance. DNA was extracted from clams derived from two geographically segregated populations and deployed in the same enzootic site in Massachusetts. The analysis contrasted samples collected before and after undergoing QPX-related mortalities. As a result, around 200 genes displayed significant variant enrichment at each sampling point including 18 genes shared between both populations. Markers depleted in survivors from both populations were in genes related to apoptosis pathways, suggesting a role for apoptosis regulation in survivorship. Markers enriched in survivors from both populations were found in genes related to protein-protein interactions, receptors, and signaling. Although more research is needed to identify the precise physiological mechanisms

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linked to resistance, our study will help develop selective breeding for resistant stocks.

46-6 Farhat, E*; Turenne, ED; Choi, K; Devereaux, MEM; Pamenter, ME; Weber, JM; University of Ottawa, Ottawa, ON, Canada; *efarh086@uottawa.ca*

Champions of hypoxia tolerance adjust membrane cholesterol and downregulate metabolism to cope with chronically-low oxygen

Some unique vertebrates are able to survive prolonged hypoxia via strong metabolic suppression. We have investigated potential mechanisms used by goldfish and naked mole-rats (NMR) to support this essential hypometabolic response. Key enzymes of energy metabolism and Na/K-ATPase were examined together with membrane composition because membrane remodeling is known to regulate trans-membrane proteins in vitro. The effects of 4 weeks of hypoxia on metabolic rate, energy metabolism, Na/K-ATPase and membrane composition were quantified in different tissues. Common responses of both species were: (1) 34-74% decrease in metabolic rate; (2) large changes in membrane cholesterol (90% increase in muscle; 53% decrease in liver); and (3) 40-77% decrease in brain Na/K-ATPase activity. Brain cholesterol also decreased by 26% in NMR, but it remained unchanged in goldfish. NMRs downregulated flux capacities for glycolysis, beta-oxidation and tricarboxylic acid cycle in all tissues except for beta-oxidation in brain. Enzymes of goldfish energy metabolism responded with more variability and they were tissue-specific. This study shows for the first time that chronic hypoxia can remodel membrane lipids in vivo. Changing membrane lipids could be a novel mechanism to promote metabolic suppression, but a clear functional link between membrane restructuring and hypometabolism could not be established. A common membrane signal regulating the inhibition of ion pumps and ion channels could be an exquisite way to preserve the balance between ATP supply and demand in the hypometabolic state, and it could serve as a neuroprotective mechanism in the brain.

44-11 Farrar, VS*; Flores, L; Ornelas Pereira, L; Mushtari, S; Viernes, RC; Calisi , RM; University of California, Davis, UC Davis; *vsfarrar@ucdavis.edu*

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Can mating behaviors be maintained in the face of elevated prolactin levels driving parental care? Revisiting the anti-gonadal effect

In many species, parents may experience tradeoffs between caring for their current brood and exhibiting mating behaviors to begin future reproductive efforts. We examined whether a physiological mediator of parental care, the hormone prolactin, can affect such a reproductive behavioral trade-off. To do this, we experimentally elevated prolactin levels in a biparental bird, the rock dove (*Columba livia*), after nest loss, from which these birds typically transition from a parental state back to courtship behaviors. Both male and female rock doves exhibit parental care, as well as "lactate" to feed young. We previously found that prolactin-treated doves maintained a parental response to novel chicks after nest loss, compared to vehicle-treated birds. We thus hypothesized that if prolactin maintains a parental state, then it would also delay pairs in their progression through the courtship cycle as they restart their next nest. We further hypothesized that this effect on reproductive behavior would be mediated by changes in gene expression in the hypothalamic-pituitary-gonadal (HPG)reproductive axis. Here, we found that six days after nest removal, prolactin did not significantly affect mating behaviors such as courtship and copulation rates. However, while prolactin did not appear to affect hypothalamic gene expression, neuropeptide receptors in the pituitary and gonadotropin receptors in the male, but not the female, gonads increased with prolactin treatment. This suggests that the HPG axis may be able to maintain reproductive behaviors despite elevated prolactin by compensating with increased responsiveness to hormonal signals. These studies shed light on how continuously-breeding animals may be able to maintain other reproductive functions during parental care.

105-4 Fath, M*; Polavaram, T; Donahue, J; Nguyen, S; Tytell, E; Tufts University, Boston College, Boston College; *michael.fath@tufts.edu*

Center of mass and center of buoyancy dynamics in the bluegill (Lepomis macrochirus)

"Fish are statically unstable." This statement is often the starting point for discussions about stability in fishes. Its

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validity is immediately accepted by both scientists and children. Both have seen that when their test subjects or pets are anesthetized or die, they tend to go "belly up." Without using their fins constantly, many species of fishes are unable to maintain a dorsal-side up orientation. The mechanism behind this instability has also been proposed. A buoyant force pushes up on the fish at its center of buoyancy (COB), which is thought to lie below the center of mass (COM). Like a pencil standing on its point, this configuration is unstable; any small deviation causes a torque that tends to flip the fish upside-down. While this mechanism makes sense, we have relatively little data on the true locations of these two critical points in different species or the torques generated from their displacement. Moreover, many fish can adjust the buoyant force and the distance between COM and COB by inflating their swim bladders. We used computed tomography (CT) scans and photogrammetric imaging to construct 3D models of several species of fishes to locate the COM and the COB of each individual. Using photogrammetry, we found variation between species. In trout, COM is indeed below COB, but in bluegill, for instance, COM is in front of COB, not below, and in perch, COM is diagonally below and in front of COB. For all species examined, the distance between the two points was quite small, resulting in small destabilizing torques. Here we present results based on CT scans on the role of the swim bladder in controlling the distance between COM and COB.

83-6 Faulkner, PC*; Elsey, R; Hala, D; Petersen, LH; Texas A&M University at Galveston, Louisiana Department of Wildlife and Fisheries; *patcfaulkner@tamu.edu*

Physiological effects of salinity stress in wild American alligators (Alligator mississippiensis)

Coastal Gulf of Mexico habitats are susceptible to saltwater intrusion from storm surges, drought, and human development altering freshwater flow. Alligators living in these habitats have low tolerance to saltwater due to their inability to excrete high sodium (Na^+) concentrations. Previous research has demonstrated that long- (5 weeks) and short-term (1 week) 12‰ saltwater exposure significantly alter regulation of salt/water balance and cause disruptions of sex steroid hormones in juvenile alligators. This study investigates whether similar physiological effects occur

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in juvenile and sub-adult wild alligators caught in varying salinities (0.4 to 22.2‰). To this end, blood plasma samples obtained from alligators sampled in Grand Chenier, Louisiana were analyzed for concentrations of 15 hormones (renin-angiotensin-aldosterone system hormones, glucocorticoids, progestogens, androgens, estrogens) via liquid chromatography and tandem mass spectrometry (LC-MS/MS). Plasma samples were further analyzed for levels of various blood plasma biochemistry parameters (electrolytes, liver enzymes, proteins, glucose, cholesterol). The multivariate analyses of all blood chemistry parameters showed seasonal variations in select parameters and significant positive correlations for selected steroid hormones and blood sodium and chloride ion concentrations in juvenile wild alligators. Further understanding seasonal variation of various biomarkers and salinity's effects on alligator physiology will better inform management decisions regarding wild alligator populations.

58-3 Feller, KD*; Mierow, T; Gonzalez-Bellido, PT; Union College, University of Minnesota; *fellerk@union.edu*

Prey size selection and visual acuity in toe-biters (Belostomatidae)

Ambush, or sit-and-wait, predation is a tactic used by both vertebrates and invertebrates. Though this is a common predation strategy, the sensory cues that trigger an ambush strike are poorly understood in many ambush performing systems. One such system, the belostomatids (known as water bugs or toe-biters), cryptically wait in the vegetation of lentic systems (i.e. vernal pools, ponds, lakes) for an appropriate target to strike, restrain, and consume. We tested the strike response to artificial prey stimuli (black glass beads) using two North American belostomatid species, Belostoma flumineum and Lethocerus americanus. We found that the smaller species (B. flumineum) reaches its maximum strike probability when presented with 2.9 mm diameter beads (12% of body length), whereas the larger species (L. americanus) will strike objects between 10mm and 35 mm diameter (58% of body length) with similar maximum probability, indicating less of a discrete preference for prey size. The difference in strike response between the two species provides a paradigm for probing how sensory systems are tuned to elicit similar behavior responses to different

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stimuli. To test for differences in specialization at the level of the sensor, we used microCT and morphometric light-microscopy methods to determine the visual acuity of the two species. We hypothesized that the visual system of each species optimally resolves an image of the given size and distance matched to the animal's maximum strike probability behavior. Future research will probe mechanisms of target selection in other sensory dimensions (i.e. mechanoreception) as well as at the level of the nervous system.

BSP-3-6 Ferguson, QR*; Leininger , EC; New College of Florida ; *quinn.ferguson16@ncf.edu*

Effects of atrazine on the gonads and vocal behavior of Silurana tropicalis

The common herbicide atrazine is a known endocrine disruptor. In the African clawed frog, *Xenopus laevis*, developmental exposure to atrazine from the tadpole stage to adulthood induces gonadal abnormalities, decreases laryngeal size, and lowers reproductive fitness. However, studies have not yet investigated how postmetamorphic juvenile atrazine exposure affects vocalizations, which are sexually dimorphic in African clawed frogs. We hypothesized that juvenile exposure to atrazine in the species *Silurana tropicalis*, an African clawed frog closely related to X. laevis, would feminize the vocal circuit by increasing the call inter-pulse interval or abolishing calling entirely, and decreasing laryngeal mass, as well as altering gonadal morphology. We performed two experiments, exposing juvenile *S. tropicalis* to either atrazine or a vehicle control from immediately after metamorphosis to maturity (Experiment 1 = 7 months, Experiment 2 = 9 months). Both experiments involved exposure to a high dose of atrazine (10 parts per billion) and a vehicle control, with the second experiment also involving exposure to a lower dose of atrazine (2.5 ppb). Males exposed to either dose of atrazine had unaltered call sound pulse rates and laryngeal masses, relative to control males. However, we detected multilobed testes in some males exposed to 10 ppb and 2.5 ppb atrazine. These results imply that juvenile exposure to tested concentrations of atrazine alters male sexual anatomy, but not the specific sexually-dimorphic behavior investigated. Future studies are required to determine whether

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atrazine more subtly affects vocal behavior, such as by changing the average number of calls per recording or average inter-call interval.

S1-1 Ferguson, SM*; Alaasam, VJ; The College of Wooster, University of Nevada - Reno; *stferguson@wooster.edu*

Light at night in the spotlight: an introduction to the symposium

Across the tree of life organisms have evolved in environments with a predictable rhythm of light and dark. Master clocks in the individual integrate daily light cues to organize genetic, physiological, and behavioral outputs. Artificial light at night disrupts those patterns and has far-reaching consequences for species of all chronotypes. Though most abundant in urban environments, the effects of light pollution are far-reaching into rural and remote natural areas. Furthermore, the intensity, spectral composition, and source of light pollution can lead to species-specific responses, complicating effects at the level of ecosystems. A brief introduction will overview the wide range of consequences of artificial light at night and introduce the major themes of our invited speakers. This symposium showcases an eclectic selection of comparative research from varied fields of study including development, physiology, population biology, and ecology. We aim to identify common mechanisms, challenges, and avenues for future research by bringing together speakers and attendees with diverse and complementary research programs.

50-1 Fernandes Gyorfy, M*; Conover, J; Grover, C; Miller, E; Wendel, J; Sharbrough, J; Sloan, D; Colorado State University, Fort Collins, CO, Iowa State University, Ames, IA; *mgyorfy@gmail.com*

Cytonuclear stoichiometry in the wake of genome duplication

The plant genome is partitioned across three distinct cellular compartments: the nucleus, mitochondria, and chloroplasts. Interactions between nuclear-encoded gene products and those of cytoplasmic genomes (*i.e.*, cytonuclear interactions) underlie the essential cellular processes such as respiration and photosynthesis. Whole genome duplication events (WGDs) are a prominent process of diversification in eukaryotes and are expected to perturb cytonuclear interactions in two fundamental ways:

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altering the genetic stoichiometry of cytonuclear interactions and increasing cell size. Organelle size, organelle genome copy numbers, cytonuclear transcriptomic and proteomic stoichiometry, and ultimately the efficiency of carbon fixation and ATP production might all be altered as a consequence of WGD, but many decades of careful investigation into polyploidy have yet to fully evaluate these predictions. We investigated the relationship between nuclear and organelle genome copy numbers in common-garden reared diploid and polyploid accessions of both wheat and *Arabidopsis*. Our droplet digital PCR (ddPCR) estimates of nuclear, mitochondrial, and chloroplast genome copy numbers revealed evidence of substantial intra-specific and intra-individual variation for organelle genome copy number, as well as evidence that polyploids exhibit elevated organelle genome copy numbers per cell. Taken together, our results indicate that polyploids appear to compensate for increased nuclear genome content with increased organelle genome copies in both monocots and dicots, indicating that cytonuclear stoichiometry is an important component of successful interactions between nuclear and cytoplasmic genomes.

43-3 Fernandez Ajó, AA*; Hunt, KH; Sironi, M; Uhart, M; Rowntree, V; Giese, AC; Marón, CF; DiMartino, M; Dillon, D; Buck, CL; Northern Arizona U/ICB, Smithsonian-Mason School of Conservation, ICB/Diversidad Biológica IV, UN Córdoba/Southern Right Whale Health Monitoring Program, Southern Right Whale Health Monitoring Program/School of Veterinary Medicine, U of California Davis, U of Utah/Ocean Alliance , Centro Nacional Patagónico CONICET, ICB/Diversidad Biológica IV, UN Córdoba, Southern Right Whale Health Monitoring Program, Northern Arizona U; *aaf269@nau.edu*

Retrospective analysis of the lifetime endocrine response of southern right whale calves to gull wounding and harassment: a baleen hormone approach

Physiological measurements provide evidence of stressors that impact the health of wildlife. Baleen, the feeding apparatus of whales, accumulates hormones as it grows allowing retrospective assessment of long-term trends in a whale's physiology. In Patagonia, Argentina, Kelp Gulls, *Larus dominicanus* (KG), have learned to parasite on living southern right whales, *Eubalaena australis* (SRW) which results in constant harassment and sizable

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wounds. With the increasing frequency of gull attacks, and a marked preference of KG to harass calves, the SRW population off Península Valdés (PV) experienced a period of elevated calf mortality that peaked in 2012. We quantified lifetime patterns of glucocorticoids (GCs, an index of general physiological stress) and thyroid hormone (T_3, an index of metabolic stress) in baleen recovered at necropsies of 36 SRW calves (~ 1 and 4 months old) with varying severity of KG lesions. GC levels correlated positively with the degree of wounding, while T3 remained stable irrespective of the severity of KG lesions. Our results suggest no evidence of malnutrition in mildly vs. severely wounded calves. However, the positive correlation of GCs with lesion severity indicates that heavily wounded calves suffered high levels of physiological stress throughout their short lifespans. Thus, KG wounding and harassment may have contributed to the high SRW calf mortality observed at the PV calving ground.

87-2 Field, DJ*; Benito, J; Chen, A; Jagt, J; Ksepka, DT; University of Cambridge, Natural History Museum Maastricht, Bruce Museum; *djf70@cam.ac.uk*

The oldest modern bird fossil, and the early evolutionary history of crown group birds

Our understanding of the earliest stages of crown bird evolution is hindered by an exceedingly sparse Mesozoic fossil record. The most ancient phylogenetic divergences among crown birds are known to have occurred in the Cretaceous, but stem lineage representatives of the deepest crown bird subclades—Palaeognathae (ostriches and kin), Galloanserae (landfowl and waterfowl), and Neoaves (all other extant birds)—are entirely unknown from the Mesozoic. As a result, key questions related to ancestral crown bird ecology, biogeography, and divergence times remain unanswered. Here, we report a new Mesozoic fossil that occupies a position close to the last common ancestor of Galloanserae, filling a key phylogenetic gap early in crown bird evolutionary history. *Asteriornis maastrichtensis*, from the Maastrichtian of Belgium, is represented by a nearly complete, three-dimensionally preserved skull and associated postcranial elements. The fossil represents one of the only well-supported crown birds from the Mesozoic Era, and is the first Mesozoic crown bird with well represented cranial remains. *A.*

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maastrichtensis exhibits a heretofore undocumented combination of galliform (landfowl)-like and anseriform (waterfowl)-like features, and, along with a previously reported *Ichthyornis*-like taxon from the same locality, provides the first direct evidence of co-occurring crown birds and avialan stem birds. Its occurrence in the northern hemisphere challenges biogeographic hypotheses of a Gondwanan origin of crown birds, and its relatively small size and possible littoral ecology may corroborate recently proposed ecological filters influencing crown bird persistence through the end-Cretaceous mass extinction.

91-2 Fifer, JF*; Yamakita, T; Yasuda, N; Davies, SW; Boston University, Japan Agency for Marine-Earth Science and Technology, University of Miyazaki; *jfifer@bu.edu*

Genetic consequences of coral range expansion

Poleward range expansions of corals in response to warming oceans have been historically observed, however contemporary expansion rates of some coral species are much more rapid as global temperatures rise at unprecedented rates. Range expansion can lead to reduced genetic diversity and surfing of deleterious mutations in expanding populations, in turn potentially limiting the ability for the species to adapt and persist in their new environment. Expansions that overcome these population bottleneck pressures and successfully colonize are attributed to multiple introductions from different sources, hybridization with native populations, or rapid adaptive evolution. Here, we investigate population genomic patterns of the reef-building coral *Acropora hyacinthus* along a latitudinal cline that includes a well-established range expansion front in Japan using 2bRADseq. A total of 184 coral samples were collected across 7 sites spanning from ~24° N to its northern range front at ~33° N. We find evidence of bottleneck pressures associated with expansion events including higher clonality, linkage disequilibrium, mutation load and lower genetic diversity in range edge populations as well as asymmetric migration between populations. We also describe genomic signatures of local adaptation possibly attributed to lower winter temperatures experienced at the more recently expanded northern populations. Together these data illuminate the genetic repercussions of range expansion in a coral and highlight how limited dispersal and/or

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adaptation to colder temperatures along the expansion front may facilitate further range expansions in this population.

S7-10 Figon, F*; Hurbain, I; Heiligenstein, X; Trépout, S; Medjoubi, K; Somogyi, A; Delevoye, C; Raposo, G; Casas, J; IRBI, UMR 7261, CNRS - Université de Tours, Tours, France, Institut Curie, UMR 144, CNRS - Université PSL, Paris, France, CryoCapCell, 80, rue du Général Leclerc, Kremlin-Bicêtre, France, Institut Curie, Inserm U1196, UMR 9187, CNRS - Université Paris-Saclay, Orsay, France , Synchrotron SOLEIL, Saint-Aubin, Gif sur Yvette, France; *florent.figon@univ-tours.fr*

Within-cell cycle of endolysosome-related pigment organelles in crab spiders leads to reversible color changes

Reversible color change is a fascinating ability of animals. Pigment-based mechanisms enabling morphological color changes are widespread in vertebrates and invertebrates. Yet, how pigment cells accommodate both formation and degradation of pigments for reversibility is not understood. In this presentation, we show how crab spiders alternate between yellowing and bleaching phases through the intracellular processing of pigment organelles. By performing electron and Synchrotron-based microscopies, we obtained ultrastructural and chemical evidence that pigment organelles are endolysosome-related organelles (ELRO), a family of organelles comprising vertebrate melanosomes. Our results suggest that yellowing of crab spiders arises from the formation of intraluminal fibrils and the deposition of metals within pigment ELROs. In contrast, bleaching appears to proceed via lysosomal degradation of intraluminal content and metal removal. Some of these intracellular processes mirror the biogenesis of other pigment ELROs, identifying endolysosomal organelles as a universal pigmentation platform. Overall, crab spiders offer a striking example of how the endolysosomal system has been fully functionalized, from anabolism to catabolism and recycling, to allow reversible morphological color changes.

S7-1 Figon, F*; Casas, J; Deravi, L; IRBI, UMR 7261, CNRS - Université de Tours, Tours, France, Department of Chemistry and Chemical Biology, Northeastern University, Boston, MA,

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Introduction to the symposium: The integrative biology of pigment organelles

Coloration is one of the most striking features of organisms in Nature and is associated to a breadth of biological functions, from visual signaling, photoprotection to detoxification. Animals and plants achieve such a diversity of tints and shades by using both structural (physical) and pigmentary (chemical) mechanisms. While these two mechanisms were classically studied rather independently, the recent years have shown that they could act in concert at the scale of subcellular organelles. Because pigment organelles can vary in content, shape, size, density and position, they bring together physical (scattering) and chemical (absorption) processes. In technological fields, these features have been repurposed for designing more efficient optical devices and new color-changing materials. Pigment organelles also hold a central position in the intracellular and physiological environment, as exemplified by the number of pathologies in which they are involved. Studying the integrative biology of pigment organelles is therefore key to understand their optical activity in relation with their many biological functions and technological applications. In this introductory presentation, we highlight how comparative, multiscale and interdisciplinary studies, led by ecologists and cell biologists to physicist and chemists, have provided a framework to unravel the proximal and ultimate causes of coloration from spiders and cephalopods, up to humans and plants. We also point out the major gaps and key questions in the pigment organelle field that should be addressed in the coming years via a collaborative effort of scientists from all disciplines.

88-2 Figueiredo, AC*; Titon, SCM; Titon, BJ; Vasconcelos-Teixeira, R; Barsotti, AMG; Gomes, FR; Universidade de São Paulo- Instituto de Biociências, São Paulo, Brazil; *aymam.figueiredo@gmail.com*

Systemic hormonal and immune regulation induced by intraperitoneal LPS injection in bullfrogs (Lithobates catesbeianus)

Host´s defense against external challenges activates an inflammatory response which is regulated by a set of chemical signals, including hormones. These immunomodulatory hormones, such as corticosterone, testosterone, and melatonin, trigger the

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systemic immune responses which are responsible for inflammatory assembly and resolution. The aim of this study was to investigate the effects of an immune challenge on endocrine and innate immune responses in the Bullfrog (*Lithobates catesbeianus*). Adult males were intraperitoneally injected with LPS (2 mg/kg) or saline and blood samples were collected 6 and 24 hours after injection for measurement of neutrophil/lymphocyte ratio, blood leukocyte phagocytosis, plasma bacterial killing ability and plasma levels of corticosterone, melatonin, and testosterone. Our results showed LPS-induced increased neutrophil/lymphocyte ratio and leukocyte phagocytosis, as well as, decreased melatonin and testosterone plasma levels, which were more pronounced 24 h after injection. Overall, we conclude that LPS intraperitoneal injection is able of activating innate immune response and modulating the hormonal profile of the Bullfrogs, with effects more pronounced 24 h than 6 h after treatment.

43-8 Filzen, RC*; Banday, Z; Greenberg, JT; University of Chicago; *rfilzen@uchicago.edu*

Dynamic Bayesian network models of Arabidopsis thaliana transcriptome time series data reveals possible role for HyPRPs in systemic acquired resistance

As climate change progresses, plants suffer increasing levels of environmental stress, commonly pathogen stress. Understanding how plants combat pathogen stress thus represents a critical area of research. Systemic acquired resistance (SAR) is one plant defense mechanism and can be conceptualized into two stages: the priming stage and the resistant stage. The priming stage is induced by a primary pathogen infection in a lower leaf triggering defense chemical biosynthesis, particularly in the chloroplast. Defense chemical transport to aerial leaves produces the resistant state in which these leaves are more resistant to secondary pathogen infection. HyPRPs are a novel protein family thought to be involved in SAR due to their unique structure and chloroplast localization. The N-terminal hydrophobic domain, proline rich region, and lipid transport protein-like domain, are predicted to give rise to their novel bipartite localization mechanism. This project uses the model organism *Arabidopsis thaliana* to investigate how HyPRPs might be involved in both the priming and resistant stages of SAR. In silico

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methods using Arabidopsis transcriptome data were used to generate predictions for protein interactions and involvement in the priming stage of SAR. These models will be used to further guide experiments and prioritize specific HyPRPs for future wet-lab assays. In vivo assays such as transient expression, SAR challenge in hyprp knockouts, and fluorescence localization microscopy reveal how HyPRPs may act in SAR responses and the impact of their structural domains in subcellular localization. Together, these two approaches to protein characterization will further the understanding of pathogen stress response in plants.

S5-8 Fish, FE*; Rybczynski, N; Duff, CM; West Chester Univ., Canadian Museum of Nature; *ffish@wcupa.edu*

Evolution of the tail and lack thereof for aquatic propulsion in mammals

Aquatic mammals exhibit a diversity of swimming modes that use paired limbs and/or tail. Muskrat, desmans, and giant otter shrew employ lateral tail undulations. However, some specialized aquatic mammals use dorsoventral (DV) tail movements for swimming. To understand the evolution of DV tail movements in fully aquatic mammals (cetaceans and sirenians), we examine swimming kinematics in the semiaquatic beaver (*Castor*), and giant river otter (*Pteronura*), which possess dorsoventrally flattened tails. Results show DV tail undulations are associated with submerged swimming for both taxa. Tail waves increase in amplitude toward the tail tip, moving posteriorly at a velocity faster than the anterior motion of the body to generate thrust. Fleshy lateral extensions along the tail increase the mass of water accelerated posteriorly and affect vorticity shed into the wake. During rectilinear swimming for thrust augmentation DV undulations of the tail are associated with simultaneous paddling strokes of the webbed hind feet. This propulsive pattern may emulate intermediate evolutionary stages toward the derived swimming mode and expanded tail flukes of ancestral cetaceans and sirenians from long robust tails. Intriguingly, the earliest "otter-like" pinnipedimorphs (*Puijila*) also possessed long tails, even though modern pinnipeds have small tails and swim by oscillation of flippers only. We suggest that transitional, tailed pinnipedimorphs did not use their tails for swimming. Possibly tail reduction and eventual loss in the early

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stages of this lineage is associated with evolution at higher latitudes. Possession of DV tail undulations, or lack thereof, guided aquatic mammals into different evolutionary trajectories for high thrust and efficient propulsion.

20-3 Fisher II, A*; DeGrandi-Hoffman, G; Smith, BH; Fewell, JH; Harrison, JF; Arizona State University, USDA-ARS; *afishe16@asu.edu*

A widely used mito-toxic fungicide negatively affects honey bee (Apis mellifera) hemolymph protein and vitellogenin levels

The honey bee (*Apis mellifera*) is an essential contributor to crop pollination but has been undergoing population declines in part due to pesticide contaminants in the foraging environment. In particular, honey bees frequently encounter fungicides as they are applied to crop plants during bloom. To assess the effects of the widely used fungicide Pristine® (25.2% boscalid, 12.8% pyraclostrobin) we subjected colonies to doses of the fungicide reflecting levels detected in almond orchards. Chronically exposed hives experienced reduced worker populations and increased winter mortality. We also observed elevated rates of pollen foraging and consumption, potentially indicating impaired protein processing. In this study, we partially tested the hypothesis that Pristine® induced negative effects on protein digestion or absorption, as indexed by hemolymph protein levels. Colonies were continuously fed pollen containing four doses of Pristine® ranging from 0.23 to 230 ppm. Pristine® consumption resulted in lower hemolymph protein levels, and the effect increased with bee age. Chronic Pristine® consumption also induced precocious foraging and reduced longevity. Together, these findings support the hypothesis that fungicides such as Pristine® negatively impact honey bee health at least partly by impairing protein balance. This research was supported by USDA 2017-68004-26322.

86-5 Fiskum, EM*; Pearson, LE; Weitzner, EL; Petch, S; Rotella, J; Schroth-Glanz, M; Glanz, H; Liwanag, HEM; California Polytechnic State University, San Luis Obispo, Montana State University; *efiskum@calpoly.edu*

Development of apneustic breathing in Weddell seal (Leptonychotes weddellii) pups

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The ability to perform prolonged apnea (breath hold) is a key adaptation in diving mammals. Pinnipeds (e.g., seals and sea lions) are known to practice apnea on land, and the ability to extend breath hold duration tends to increase with ontogeny. In this study, we describe the development of apneustic breathing in the Weddell seal (*Leptonychotes weddellii*), a deep-diving species, throughout the dependence period. We hypothesized that both age and early experience in the water would influence the development of apneustic breathing in this species. To test this, we characterized the respiratory patterns of known-age Weddell seal pups (n=19) using video footage of pups hauled out of the water and resting on ice, every 1-2 weeks from 1 week through 7 weeks of age. We quantified eupneic (i.e., normal) respiration rate (breaths/min), presence/absence of apneustic breathing, and apneustic interval (length of breath hold) for each recording. We found that most animals did not perform apnea until after their first entry into the water, and that apneustic interval was significantly positively correlated with age (r^2=0.245, P=0.0012). These results are consistent with early developmental patterns in other pinnipeds, and further, this is the first study to correlate physiological development with early behavioral experience in the water. Future work will correlate apneustic interval with dive depth and duration for a subset of pups (n=9) from the current study.

96-3 Fitak, RR; University of Central Florida; *robert.fitak@ucf.edu*
Symbiotic magnetic sensing in animals: evidence from metagenomics
It is well-known that numerous animals, from arthropods to vertebrates, can sense Earth's magnetic field and use this information to guide their movement. However, the specific mechanism responsible for a magnetic sense remains enigmatic. Although several putative mechanisms of magnetic sensing are often studied, a new, potentially unifying hypothesis has recently been proposed. This hypothesis posits that specific bacteria, called magnetotactic bacteria, are responsible for a magnetic sense through a symbiotic relationship with a host animal. More specifically, these bacteria, which manufacture their own chains of magnetite crystals to sense Earth's magnetic field, could reside in specific nervous system tissues of animals and communicate magnetic information to the host. This presentation will summarize the

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hypothesis and discuss preliminary supporting data collected from metagenomic databases. This work combined with future experimental evidence will provide critical data to improve the understanding of how organisms use Earth's magnetic field to inform their movements and the various novel ways in which symbiotic microbes govern important physiological traits of a host.

4-1 Flammang, BE*; Marras, S; Anderson, EJ; Lehmkuhl, O; Mukherjee, A; Cade, DE; Beckert, M; Nadler, JH; Houzeaux, G; Vázquez, M; Amplo, HE; Calambokidis, J; Friedlaender, AS; Goldbogen, JA; NJIT/Rutgers University, NJIT, Woods Hole Oceanographic Institution, Barcelona Supercomputing Center, Stanford University, Georgia Tech Research Institute, Cascadia Research Collective; University of California Santa Cruz; *flammang@njit.edu*

Remoras pick where they stick on blue whales

Animal-borne video recordings from blue whales in the open ocean show that remoras preferentially adhere to specific regions of the surface of the whale. Using empirical and computational fluid dynamics analyses, we show that remora attachment was specific to regions of separating flow and wakes caused by surface features on the whale. Adhesion at these locations offers remoras drag reduction up to 71-84% compared to the freestream. Remoras were observed to move freely along the surface of the whale using skimming and sliding behaviors. Skimming provided drag reduction as high as 50 - 72% at some locations for some remora sizes, but little to none was available in regions where few to no remoras were observed. Experimental work suggests that the Venturi effect may help remoras stay near the whale while skimming. Understanding the flow environment around a swimming blue whale will inform the placement of biosensor tags to increase attachment time for extended ecological monitoring.

91-9 Flanagan, BA*; Li, N; Edmands, S; University of Southern California; *bflanaga@usc.edu*

Mitochondrial effects on sex-specific aging and age-related phenotypes in a copepod without sex chromosomes

Mitochondria, as the center for energy production, perform the biochemical transformation of glycolysis products to generate

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usable energy in the form of ATP. Mitochondrial malfunction can lead to senescence and aging phenotypes. Theory predicts degenerative phenotypes and metabolic diseases associated with mitochondria may occur more frequently in males than females due to the matrilineal inheritance pattern of mitochondrial DNA (mtDNA). Mitochondrially driven senescence may be caused by the overproduction of reactive oxygen species generated by oxidative phosphorylation inefficiencies which may damage both mtDNA and nuclear DNA, exacerbating the aging phenotype. Here we estimate sex-specific longevity for parental and reciprocal F1 hybrid crosses between two allopatric *Tigriopus californicus* populations which display over 20% mtDNA divergence. *T. californicus* is an emerging model system used to estimate the mitochondrial contribution to sex-specific aging because disparate populations have high divergence, yet remain viable when crossed, and they lack sex chromosomes allowing for more direct testing of mitochondria in sex-specific aging. Along with estimating sex-specific longevity, we estimate aging and damage related phenotypes including mtDNA content and 8-OH-dG DNA damage 28 and 56 days post-hatch. Overall, males live longer than females yet the sex-difference depends on the mitochondrial genotype. Males have lower mtDNA content which decreases with age. Interestingly, males show an increase in 8-OH-dG DNA damage with age while females do not. Hormetic effects in males where an intermediate amount of cellular stress or damage is beneficial may help to explain the relationship between increased DNA damage and increased lifespan when compared to females.

97-5 Fleming, RC*; Hoke, KL; Colorado State University; *rachel.c.fleming@colostate.edu*

a 3d finite element model for sound transmission in an amphibian middle ear

The ancestors of modern-day amphibians were the first vertebrates to evolve a middle ear for land-based hearing. Today's amphibians retain a simple and effective middle ear structure similar to those of their ancestors. The fundamental mechanisms of these ears may reflect those that served as foundations of hearing in terrestrial vertebrates. Understanding amphibian hearing mechanisms can therefore offer insights into the evolution of more sophisticated hearing we observe in land-dwelling vertebrates today. Although the

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anatomy of the amphibian middle ear has been thoroughly described, it is not known to what extent various anatomical properties, such as material properties or shape and size of ear structures, influence sound transduction. To study how these factors may influence hearing, I created a 3D finite element (FE) model of a frog middle ear from a diceCT scan. I segmented middle ear parts from the scan, processed them into a volumetric FE model, and created a finite-element simulation. I am now subjecting this model to harmonic response simulations at a range of frequencies and measuring the sensitivity of the model to changes in various properties to determine which parameters most influence sound transfer to the inner ear. We are currently using this model to better understand the biomechanics of hearing in amphibians and how variation in the middle ear affects sound transmission. Advancing knowledge of amphibian hearing may provide insights into fundamental principles of hearing in terrestrial vertebrates.

89-6 Floreste, FR*; Ferreira, LF; Titon Jr, B; Titon, SCM; Muxel, SM; Gomes, FR; Assis, VR; University of Sao Paulo, Santo Andre Foundation University Center; *felipe.floreste@gmail.com*

Temporal variation of cytokine gene expression during the inflammatory response in toads

Corticosterone (CORT) and melatonin (MEL) are hormones with complex immunomodulatory effects, including alterations in the temporal pattern of cytokine production. Cytokines are essential for advance and resolution of the inflammatory response. Pro-inflammatory cytokines (IL-1β and IL-6) provide leukocyte recruitment and activation for initial stages of the response, while anti-inflammatory cytokines (IL-10) inhibit the advance of inflammation at later stages, protecting against autoimmune damage. However, the dynamic of the inflammatory response is still underexplored in ectotherms. We investigated the progression of the inflammatory response in toads (*Rhinella diptycha*) injected with lipopolysaccharide (LPS; 2mg/kg) or saline. Toads were bled (1, 3, 6, and 18h post-injection) to measure CORT and MEL levels, and spleens collected to quantify cytokine mRNA expression. Our preliminary results for 1 and 6h post-injection show increased CORT and decreased MEL in LPS-treated toads compared to saline-treated 6h post-injection. We also found IL-1β and IL-6 upregulation in

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both 1h and 6h, but IL-10 was detected only 6h post-injection in LPS-treated toads. Alterations in CORT and MEL levels indicate activation of the hypothalamus-pituitary-interrenal axis and possible existence of the immune-pineal axis in amphibians, respectively. The cytokine expression pattern agrees with inflammatory progress since pro-inflammatory cytokines were expressed in both time-sets and the anti-inflammatory cytokine only in 6h. In further analysis, we expect higher IL-6 values and similar hormone levels in 3h, while for 18h, we predict lower IL1-β, IL-6, and MEL levels, followed by higher IL-10 and CORT levels in LPS-treated toads.

12-4 Fofanova, E*; Voronezhskaya, E; Koltzov Institute of Developmental Biology Russian Academy of Sciences (IDB RAS); *lizchenbio@mail.ru*

Age-related cilia shortening in marine polychaeta Dinophilus gyrociliatus

Most of the cells in a multicellular organism possess cilia. In eukaryotes, one or two cilia generally considered as sensory while tens and hundreds of cilia per cell are usually motile. Multiciliated cells (MCCs) activity drive fluid flow across an epithelium thus allow motility and feeding in small invertebrates and their swimming larvae as well as organize mucus clearance, cerebrospinal fluid circulation, and egg transportation in vertebrates. Molecular mechanisms of ciliogenesis and regulation of ciliary length are much conserved among the phyla. And MCCs dysfunction is associated with numerous diseases and loss of function in both vertebrates and invertebrates. While the initial stage of cilia formation and maintenance are studied in details less is known about the period of their loss of function during aging. Here, we present the marine polychaete Dinophilus gyrociliatus as a unique model to study mechanisms of age-related changes in ciliary cell structure. We demonstrated a decrease in cilia number per cell as well as a ciliary shortage in multiciliated cells on senior individuals of D. gyrociliatus while it was maintained in juveniles and adults. As a result, the ciliary driving locomotion of aged individuals drastically slowed down. The advantages of D. gyrociliatus are short life span, permeable epithelium, sequenced genome and easily rearing in culture. Our

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results demonstrate that D. gyrociliatus represents a perspective model to investigate cilia growth and age-related changes in both normal conditions and under various environmental and pharmacological influences. The study was supported by RFBR, projects # 19-34-60040 and #18-04-01213.

40-5 Ford, KL*; Bernt, MJ; Peterson, R; Albert, JS; University of Louisiana at Lafayette, American Museum of Natural History, University of Louisiana at Lafayette, George Washington University; *klf8880@louisiana.edu*

It's complicated: Examining convergent evolution of craniofacial morphologies in apteronotid and mormyrid electric fishes

Weakly electric fishes provide an opportunity to examine multiple instances of morphological convergence across continents. Gymnotiformes and Mormyridae use weak electric signals for prey detection, predator avoidance, and social communication. Species within each lineage inhabit deep river channels, shallow streams, and flooded plains, but it is unclear how these habitat types influence morphology. Snout length and shape are affected by prey type and availability, both of which are strongly influenced by a habitat's water velocity and habitat complexity. Two families of electric fishes, Apteronotidae (Gymnotiformes) and Mormyridae (Osteoglossiformes), exhibit a particularly high range of head shape disparity. A few studies have examined the similarities between the external morphologies of species in these two lineages, but we have yet to quantify the morphologies of internal head structures. Individuals from Apteronotidae (43 species, n=160 specimens) and Mormyridae (41 species, n=229 specimens) were analyzed using 3D geometric morphometrics with 22 homologous landmarks. Specimens were CT-scanned and analyzed using the programs 3D-Slicer and *Geomorph*. Procrustes ANOVA and multivariate regressions were used to analyze morphological similarities, which were then traced on phylogenetic trees. Ancestral trait reconstructions were performed using maximum likelihood. Results indicate multiple instances of significantly convergent morphologies, but only within families. Convergent morphologies were not found between families. These results invite further study into the roles of natural selection and developmental constraints in the production of convergent phenotypes.

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13-1 Ford, MP*; Price, CT; Santhanakrishnan, A; Oklahoma State University; *askrish@okstate.edu*

Stroke frequency and size effects in metachronal swimming

Metachronal paddling has been used by a variety of organisms over a wide range of body sizes, from the microscopic paramecia to mantis shrimp and lobsters tens of centimeters in body length. These body sizes result in a large range of Reynolds numbers and vastly different fluid dynamic effects on the paddle and body motion. Previously, it has been reported that organisms traveling with larger Reynolds numbers leave wakes detectable much longer and much farther downstream (relative to their body size and swimming speed) than smaller organisms. However, the effect of paddle-based Reynolds number on the wake direction, wake structure, and swimming speed have not been explored. Using a robotic paddling model with fixed stroke kinematics (phase lag and stroke amplitude), we vary the stroke frequency and fluid viscosity both with the model tethered and free-swimming in the longitudinal direction. Varying the stroke frequency allows us to examine the fluid dynamic effects of an organism of a certain size stroking faster or slower, while varying the fluid viscosity allows us to examine the different fluid dynamic effects acting on organisms of different sizes. We found that while the direction of the wake is not affected nearly as much with changing stroke frequency and fluid viscosity, the structure of the wake was found to vary dramatically, with higher stroke frequencies associated with less interaction in the wake from cycle to cycle, resulting in the wake from each stroke appearing as distinct periodic waves of high-speed fluid motion relative to the surrounding fluid. Flow visualization, wake momentum and swimming speed will be discussed.

52-10 Formoso, KK*; Habib, MB; University of Southern California and Natural History Museum of Los Angeles County, Natural History Museum of Los Angeles County; *formoso@usc.edu*

Potential constraint and release driven by ancestral terrestrial posture in land-to-sea transitions: Insights from forelimbs across four land-to-sea amniote clades

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Most aquatic amniotes descended from terrestrial ancestors with appendicular locomotion via an upright or sprawling posture, evolving one or a combination of axial and appendicular aquatic locomotion. To explore if ancestral posture and locomotion might influence secondarily aquatic transitions, forelimb elements of thirty transition-spanning cetaceans, mosasaurs, sauropterygians, and pinnipeds were compared. Linear measurements were taken between homologous landmarks of the scapula, humerus, ulna, corrected for size using geometric mean, and made into principal components for principal components analyses. The PCA morphospaces of cetaceans and mosasaurs, both of which have derived members utilizing axial aquatic locomotion, occupy a nearly identical range in PC1, heavily loaded to long bone length, but cetaceans occupy a significantly wider morphospace than mosasaurs along the PC2 axis, loaded to scapular measurements. This potentially suggests either constraint in certain forelimb aspects in mosasaurs, and/or a functional release in cetaceans, potentially pertaining to ancestral posture. Pinnipeds and sauropterygian forelimb morphospaces, which had different ancestral postures, do not overlap in forelimb morphospace at all, not even between early sauropterygians and pinnipeds, despite these groups being primarily appendicular swimmers and oft used as convergence examples. Further, the morphospaces of sauropterygians and mosasaurs, both ancestrally sprawling clades, but whose derived members use appendicular and axial aquatic locomotion respectively, do align and then diverge in the morphospace, potentially reflecting these locomotory changes.

98-10 Fortner, JD*; Wilken, AT; Sellers, KC; Cost, IN; Holliday, CM; University of Missouri - Columbia, University of Chicago, Albright College; *jdfyft@missouri.edu*

Finite element modeling the effect of symphyseal tissue properties and the intramandibular joint on Tyrannosaurus rex mandibular biomechanics

Feeding-related forces are thought to act as selective pressures on the mandible and thus influence vertebrate mandibular morphology. However, while a large body of work exists on the biomechanics and structure-function relationships of mammalian mandibular morphology, results may not be fully applicable to sauropsids which exhibit unfused dentary symphyses and prominent intramandibular

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joints (IMJs), whose role in mediating or redistributing mandibular strain are not yet fully appreciated. Theropods, an ecologically diverse clade within Sauropsida with great diversity in mandibular shape, are thought to have possessed kinetic mandibles and mobile IMJs. This however presents a biomechanical paradox for large osteophagous theropods like *T. rex* that must use its adductors to both produce extreme bite forces and mediate possible excursions and wishboning of the dentary about the IMJ. We use finite element modeling (FEA) to investigate how the mandible of *T. rex* was biomechanically loaded under different hypotheses of symphyseal tissue properties and mandibular adductor orientation to examine the effect of symphyseal tissues and the IMJ on its mandibular performance. Our results show similar patterns of strain and deformation regardless of symphyseal tissue type. Inverse wishboning and long axis rotation about the IMJ induced by *m. pterygoideus ventralis* and *m. adductor mandibulae externus medialis* is best reduced by a dorsomedial orientation of *m. intramandibularis* that is contiguous with *m. pseudotemporalis superficialis*.

BSP-1-7 Fortunato, JA*; Earley, RL; University of Alabama; *jafortunato@crimson.ua.edu*

Age-dependent genetic variation in aggression

Understanding the extent to which genetic variation underlies behavioral variation is key to understanding how behavior might evolve. We investigated whether genetic variance contributes to variation in aggressive behavior among individuals in mangrove rivulus fish. We also examined whether broad-sense heritability for aggression changes over a life-history transition from juvenile to adult. Rivulus provides a unique opportunity to investigate the relative contributions of genetic and environmental variance to phenotypic variation because they exist primarily as self-fertilizing hermaphrodites. This mating strategy permits natural production of nearly isogenic lineages and analysis of genetic effects on the phenotype independent of environmental effects without complex breeding designs. We hypothesized that there would be: i) age-dependent variation among genotypes in aggressive behavior and ii) aggressive behavior would differ between juveniles and adults. We quantified aggression of 8 genotypes of rivulus

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(N=64) using a 3-D printed model opponent and allowed individuals to interact with the model for 30 minutes. We tested animals four times throughout the experiment, twice as juveniles (80 and 87 days post-hatch (dph)) and twice as adults (173 and 180 dph). We found that juveniles were more aggressive than adults. We also found that aggressive behavior was repeatable in both juveniles and adults but heritable only in juveniles. Additionally, we found significant variation among genotypes (i.e, heritability) in the extent to which aggression changed over development. Although we found individual variation for aggressive behavior in both life stages, the data suggest that aggressive behavior will evolve at a higher rate in juveniles than adults when exposed to the same selection pressures.

S12-10 Foster, MS; Smithsonian Institution, Washington, DC; *fosterm@si.edu*

Leks of Tyranneutes stolzmanni provide insights into male aggregation

Despite considerable research in the last decade on lek-breeding birds, many aspects of the evolution of the lek social system remain unresolved. For example, it has been suggested that lek males aggregate because females prefer to visit groups of males rather than solitary individuals. Whether this is true or not, it addresses the issue of group maintenance rather than group origin. Originally, males had to aggregate independent of female preference so that females could then prefer the group. Initial male aggregations may have formed passively when males responded independently but concurrently to some external stimulus (e.g., a concentration of display sites, prominent food source, a travel corridor or nesting sites commonly used by females) that caused them to be drawn to a particular site at a certain time unmindful of other males. Aggregation was an unintentional by-product of that response. In contrast, male aggregation may have been active, with a male purposely seeking to associate with another male (or males) because proximity to that male allowed him to enhance his own reproductive success by improving his ability to attract females (i.e., learning from his associate) or to intercept females attracted to that male (i.e., poaching on his success). To identify factors important in the formation of male aggregations, I studied

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the Dwarf-tyrant Manakin (*Tyranneutes stolzmanni*), a species in which some breeding males occupy solitary courts where they attempt to attract females for reproduction, whereas other males occupy courts clustered into leks, where they interact to attract females. I compared habitat characteristics and resource availability at courts of these two groups as well as certain traits of males in each to gain insight into passive or active lek formation in this and the initial lek-forming species.

23-12 Fourney, E*; Sukhwani, A; Schulz, A; Hu, D; Georgia Tech, School of Mechanical Engineering, Atlanta, GA, Georgia Tech, Schools of Mechanical Engineering and Biological Sciences, Atlanta, GA; *efourney@gatech.edu*

Wrinkles and folds enable stretching of elephant trunk skin

To reach objects, the trunk can elongate by 25% of its relaxed length, and this deformation is mostly absorbed in unraveling of wrinkles and folds rather than in stretching the flat patches of skin. In this experimental study, we perform tensile tests on dissected skin from seven different sites along a deceased African elephant (*Loxodonta Africana*). We find that one wrinkle can absorb 20 percent of the strain, while a fold can absorb 90 percent of the imposed. By inputting the geometry of the wrinkles and folds into finite element simulations, we hope to predict material properties of the skin and rationalize the observed locations of folds and wrinkles. These findings may inform new bio-inspired materials that exhibit a combination of high load bearing capabilities and large axial strains without failure.

31-7 Fournier, CS*; Hart, JA; Hart, TB; Detwiler, KM; Florida Atlantic University , Frankfurt Zoological Society; *ckorchia2015@fau.edu*

Assessing the impact of hunting on the vertebrate community and the lesula monkey (Cercopithecus lomamiensis) in the Lomami National Park and buffer zone, Democratic Republic of the Congo

Camera traps (CT) are an objective method to successfully document faunal communities in tropical forests. The objective of this study was to evaluate the impact of hunting on terrestrial vertebrates with a focus on the lesula monkey (*Cercopithecus lomamiensis*) in

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the Lomami National Park (LNP) and its buffer zone, which is a remote, understudied forest in the central Democratic Republic of the Congo (DRC). Lesula is a recently discovered primate species that occupies a terrestrial niche unlike other *Cercopithecus* species and faces hunting threats in 80% of its range. We conducted four systematic, terrestrial camera trap surveys, with two sites located inside the protected Lomami National Park (LNP) (Losekola, 2014; E15, 2015) and two sites in the hunted buffer zone (BZ) (Okulu, 2013; Bafundo, 2015). We analyzed a total of 4785 events over 7210 CT days (LNP: 3751 events, 4409 CT days; BZ: 1034 events, 2801 CT days). We recorded a total of 55 vertebrate species (39 mammals and 16 birds), which demonstrates the rich biodiversity of the DRC. Using a comparative approach between protected and hunted sites, we recorded a lower capture rate for all categories of fauna in the buffer zone, but a high lesula trap rate (mean three sites = 10.0 events/100 CT days) regardless of survey site. This study provides baseline data for the continuous monitoring of the LNP vertebrate community and of the lesula monkey. Estimating the status of different populations related to hunting pressures will help in implementing hunting regulations and ensuring long-term conservation efforts of the LNP ecosystem.

BSP-3-4 Fowler, KJ*; Santymire, RM; Brown, JS; University of Illinois at Chicago, Lincoln Park Zoo, Moffitt Cancer Center; *kfowle6@uic.edu*

Determining pregnancy status in an induced ovulating mustelid (Mustela nigripes)

The black-footed ferret (BFF) is an induced ovulating mustelid that nearly went extinct in the 1980s. The US Fish & Wildlife Service established a captive breeding program with only seven genetic founders resulting in potential genetic drift issues that have led to reduced fecundity. Female BFFs can experience a pseudopregnancy after ovulation, characterized by similar hormone concentrations and behavior between pregnant and non-pregnant females. Our goal was to determine a noninvasive technique to identify pregnant and pseudopregnant BFFs. Our objectives were to compare fecal progesterone metabolites of pregnant (whelped, "W") and known pseudopregnant females (identified via ultrasound after natural

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breeding, "DNW", or not paired with a male and had ovulation induced using luteinizing hormone, "LH") using three enzyme immunoassays (EIA): an inhouse pregnane (antibody CL425), inhouse pregnanediol glucuronide (PdG; antibody P26), and commercial progesterone (Arbor Assays, Inc. #K068). For pregnane, all three groups showed significant increases post-ovulation, with LH having higher pre-and post-ovulation concentrations than W and DNW. For PdG, there was no significant change in pre- and post-ovulation in all three groups, while DNW had higher overall concentrations than W and LH. For the Arbor Assays progesterone, only the W females showed a significant increase after ovulation. In summary, the commercial progesterone EIA can distinguish between pregnant and pseudopregnant BFFs; thus, providing the first steps into determining the hormonal mechanisms of pseudopregnancy while creating a tool to assist with BFF management and conservation.

S1-5 Francis, CD; Cal Poly, Cal Poly San Luis Obispo; *cdfranci@calpoly.edu*

Heterogeneity in avian responses to light pollution from a continental perspective

Artificial night lighting is globally ubiquitous. Although recent work suggests this stressor can have a variety of consequences for wild animals, our understanding of species and context-specific variation in responses to this stimulus lags, as does our knowledge of whether effects of light exposure changes in the presence of other stressors. Here, I present results from two continental-scale studies that leveraged data from over 58,000 nest records and 3.5 million observations from citizen science efforts to understand the consequences of exposure to artificial night lighting while accounting for the influence of other aspects of human activity. Breeding birds exposed to light began nesting substantially earlier than those in dark regions and the effect was especially pronounced for open-habitat birds. Forest-habitat birds laid larger clutches with increases in light exposure. Species-specific variation in response to light was consistently explained by variation in eye geometries; birds with better low light vision advanced breeding most strongly with light exposure, but also benefit from light exposure in terms of overall nest success. In general, abundance of overwintering birds at feeders was not strongly influenced by light

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exposure, except the context of multiple stressors. Specifically, co-exposure to noise exacerbate negative responses to light and birds tended to increase in abundance with light exposure during longer winter nights. Although most species tended to increase in abundance with light exposure, the abundance of birds from forested habitats declined strongly with light exposure. Together, these results not only suggest that artificial light has widespread but heterogeneous effects on birds, but also provide important insights on the intrinsic and extrinsic factors responsible for variation in responses.

92-8 Francis, RK*; Catalano, KA; Majoris, JE; D'Aloia, CC; Ruger, T; Bogdanowicz, S; Buston, PM; Boston University, Boston, MA, Rutgers University, New Brunswick, NJ , King Abdullah University, Thuwal, Kingdom of Saudi Arabia, University of New Brunswick, Saint John, Canada, University of Exeter, UK and Boston University, Boston, MA, Cornell University, Ithaca, NY ; *rkf@bu.edu*

Breeding habitat, mating system, and mating success in the sponge-dwelling goby Elacatinus lori

Understanding the causes of variation in reproductive output is a major goal of marine metapopulation ecology. Individual reproductive output is often highly variable, and may be dependent on variation in the traits of individuals and qualities of their habitats. Here, we investigate characteristics of breeding habitat, the genetic mating system, and determinants of male mating success in the neon goby *Elacatinus lori*. This fish is found in close association with the yellow tube sponge *Aplysina fistularis* in Belize. Females lay eggs inside the sponges of males; males care for the eggs until they hatch. First, we use surveys of sponge size and occupancy status to determine the subset of sponges used by breeding males. We show that breeding males occupy a non-random subset of sponges: sponges occupied by breeding males are larger than those occupied by other residents. Second, we use genetic parentage analysis to determine the mating system. We show that *E. lori* exhibits a polygynous mating system: some males breed with multiple females simultaneously, sequentially, or both. Third, we use field observations of breeding behavior and measures of male size and sponge size to determine which factors explain variation in male mating success. We show that male size is the primary

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driver of mating success: male size is significantly and positively related to total reproductive output. This study concludes that large fathers and good homes will contribute to the population persistence of a coral reef fish.

93-5 Franklin, AM*; Rankin, KJ; Ospina-Rozo, L; Medina, I; Garcia, JE; Dong, CM; Ng, L; Wang, L-Y; Aulsebrook, AE; Stuart-Fox, D; School of BioSciences, The University of Melbourne, Australia, Bio-Inspired Digital Sensing Lab, RMIT University, Australia; *amandaf@unimelb.edu.au*

Mirror camouflage: Busting the myth

Some animals, including fish, beetles, spiders and butterfly chrysalises, have such shiny surfaces that they appear almost mirror-like. A compelling but controversial hypothesis is that a mirror-like appearance enhances camouflage by reflecting the surrounding environment. We tested the efficacy of mirror-camouflage in a complex terrestrial environment using field predation and human detection experiments. Both experiments used highly realistic mirror-green and diffuse-green models of Australian Christmas beetles, in their natural forested habitat. Of 1080 beetle models deployed at two independent forested locations, 9% were attacked but there was no difference for mirror or diffuse beetles. Similarly, there was no difference in attack frequency when beetles were deployed on open ground where mirror camouflage is ineffective. The human detection experiment required participants to wear eye tracking glasses and complete a time-limited search task for beetle models placed in the forest. Participants showed no difference in the success probability or latency to detect mirror beetles. Taken together, our results suggest that the extremely shiny appearance of Christmas beetles does not reduce the probability of detection or attack by predators. Instead, highly shiny surfaces may have evolved as a secondary consequence of selection for a non-visual function, such as water repellency or cuticle strength.

110-3 Fraser, CJ*; Butler, MA; University of Hawai'i at Manoa; *claire7@hawaii.edu*

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Evolutionary analysis of SARS-CoV-2: Is haplotype variation linked to mortality?

SARS-CoV-2 is responsible for the devastating COVID-19 pandemic, varying in degree of impact depending on geographic location. The inherently high viral mutation rate along with the large scale of viral replication across human populations has resulted in the evolution of multiple strains over time. Recently, some mutations have been identified as functionally relevant, associated with disease severity and mortality rates. I will characterize viral haplotypes via Single Nucleotide Polymorphisms (SNPs) at genomic regions with high frequencies of mutation. I will conduct a genotype analysis of SARS-CoV-2 strains (downloaded from GenBank/GISAID) following alignment and construction of a minimum spanning haplotype network using Arlequin and PopArt software. By conducting a survey of the haplotype prevalence in localities with varying levels of mortality, I can search for links between viral strain and host survival. Furthermore, the SNPs associated with each haplotype can be explored for potential functional changes that occur in the proteins coded at those genomic regions. I will examine SNPs of key functional proteins, such as those required for host entry and replication, for links to structural differences that may confer some type of viral advantage.

37-2 Freckelton, ML*; Knowles, AF; Nedved, BT; Hadfield, MG; University of Hawaii at Manoa; *marnief@hawaii.edu*

Identifying recruitment sites: How important are bacterial strain differences to invertebrate larvae?

Settlement and metamorphosis of many benthic invertebrate larvae are dependent on detection of cues from biofilm bacteria. The identity of the cues that mediate these interactions remain largely unknown. However, the same bacterial genera are repeatedly implicated in this induction across many different phyla. Earlier studies had shown that larvae of the coral *Pocillopora damicornis* were sensitive to strain differences in single bacterial species. To better understand bacterial cueing specificity, we exposed larvae of the serpulid polychaete *Hydroides elegans* and the sponge *Haliclona caerulea* to monospecific biofilms from multiple strains of the two bacterial species: *Pseudoalteromonas luteoviolacea* (4 strains) and *Thalassotalea euphilliae* (3 strains)

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isolated from inner harbor or coral reef environments. We found that larvae of *H. elegans* and *H. caerulea*, both biofouling species typical of harbors, had stronger responses to the harbor strains of bacteria. The three strains of *T. euphilliae*, all isolated from a coral reef, had different inducing effects for *P. damicornis* and *H. elegans*: each animal was induced to metamorphose by a different strain. Interestingly, the different strains of *P. luteoviolacea* also exhibited differences in the amount of violacein they produced, with the coral reef strain producing significantly higher levels of the characteristic secondary metabolite. Marine biofilm bacteria rapidly colonize new surfaces and show community-compositions that differ between habitats. We hypothesize that small, strain-specific differences in bacteria are detected by larvae of marine invertebrates to determine the suitability of a habitat for recruitment.

51-8 Fredna, K*; Reinke, BA; Northeastern Illinois University; *kelseyfredna@gmail.com*

Signal partitioning allows butterfly wing surfaces to evolve under opposing selective pressure

Signal partitioning allows butterfly wing surfaces to evolve under opposing selective pressure Fredna K[1] and Reinke BA Ph.D.[2] kelseyfredna@gmail.com Department of Biology, Northeastern Illinois University, Chicago, IL 60625 Animal coloration is typically the evolutionary compromise of two, often opposing, processes, natural and sexual selection, that is inherently dependent on the environment in which the color is viewed. Sexual dichromatism is a widespread phenomenon typically driven by sexual selection. This dorsal surface of the wing of most butterflies (Order: Lepidoptera) is only visible during flying, courtship displays, or basking, while the ventral surface is visible while resting. Given this physical separation of colors, referred to as signal partitioning, dorsal and ventral wing surfaces can potentially evolve under completely separate selective pressures; this may be evident by comparing the evolution of sexual dichromatism of dorsal and ventral surfaces. We propose that there will be more sexual dichromatism on the dorsal surface of Lepidopteran wings than on the ventral side, and that since these signals are dependent on the light under which they are perceived,

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we predict that environments with a high percentage of vegetative cover and areas with a low percentage vegetative cover would produce the most profound sexual dichromatism, while intermediate areas would have little to no sexual dichromatism. To test these predictions, we use photographs of adults of the group Biblidinae, which consists of approximately 340 identified species. We will then use phylogenetically controlled methods (PCM) to assess whether the evolution of the sexual dichromatism on the dorsal and ventral surfaces occurs independently and varies by environment as hypothesized. This work is important for understanding signal partitioning and the evolution of sexual dichromatism.

11-3 Freeman, AR*; Lo, B; Choudhry, A; Singh, B; Ophir, AG; Cornell University, Cornell University, Thomas Jefferson High School for Science and Technology; *arf86@cornell.edu*

'I'm open to it': African giant pouched rat females signal reproductive availability to potential mates and competitors via altered signal composition but not via behavior

Vaginal non-patency is a state in which the vagina is closed or fully sealed to the external world. Vaginal patency is unique among African giant pouched rat (*Cricetomys ansorgei*) females, in that patency can be delayed well past adulthood and it is reversible, independent of photoperiodic cues. In addition to altered genital morphology, non-patent females have smaller uterine horns and cervixes (traits that are generally associated with reproductive quiescence). Because non-patent females are obviously unable to copulate, we hypothesized that they would signal their reproductive state to potential mates and competitors. We predicted that patent females would scent-mark more, and that the composition of their scent marks would differ from non-patent females. We compared urine metabolites from non-patent and patent females using HPLC-MS. We found that non-patent and patent females differed in their metabolomic profiles, and discovered that the non-patent females' urine metabolome became relatively more similar to the patent females once these non-patent females had transitioned to patency. However, non-patent and patent females did not differ in their rates of scent marking, or the types of scent marks they made. Thus, patent and non-patent African giant pouched rat females do not alter signaling behavior, but they do have altered signal

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composition that likely informs competitors and mates. Given that non-reproductive females engage in scent marking, we posit that scent marking in this species may have evolved for territory maintenance and identity signaling.

8-7 Freiler, MK*; Proffitt, MR; Smith, GT; Indiana University, Bloomington; *mkfreile@indiana.edu*

Electrocommunication signals and aggression are temporally linked in an electric fish with male morphological variation

Within species variation across males is common among vertebrates and is often related to distinct reproductive strategies characterized by dramatic differences in morphology and behavior. Males with divergent reproductive tactics often use communication signals in a status-dependent way. South American weakly electric knifefish are an excellent model in which to study how male variation in morphology underlies differences in social communication during intermale contests. Knifefish produce a continuous electric organ discharge (EOD) from their tail to communicate. Fish can also transiently modulate the frequency of this discharge during courtship and agonistic encounters to produce signals called chirps. Variation in male jaw morphology is common among male knifefish and is sometimes related to variation in electrocommunication. In one species, *Compsaraia samueli*, males show striking variation in jaw length. However, EODs and chirps have never been investigated in this species, so it is unclear if jaw length is related to the production and function of chirps. Here, we use live, agonistic, dyadic encounters with males of varying jaw lengths to analyze the function of chirps. The male with longer jaws was more likely to be dominant and attacked more. Chirp rate was also positively correlated with attack rate within and between fish. Within both dominants and subordinates, chirps tended to precede attacks with a latency of 1-2s, suggesting chirps serve as aggressive signals in *C. samueli*. Even though males produced chirps in a status-dependent way, their function did not vary across status. Together, these results confirm variation in male morphology determines differences in aggression and communication.

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74-7 Fu, Q*; Astley, HC; Li, C; Johns Hopkins University, University of Akron; *fqiyuan1@jhu.edu*

Snakes traversing complex 3-D terrain

Snakes can bend their elongate body to traverse complex 3-D terrain. With the exception of sidewinding with small vertical body lifting, most previous studies of terrestrial snake locomotion used flat surfaces and focused on the role of lateral bending. Few studies tested terrain with large height variation or considered whether snakes can use vertical bending to traverse. Recent studies in our groups revealed that snakes use vertical body undulation to traverse a horizontal cylindrical array (Jurestovsky *et al.*, in prep) and combine lateral oscillation and vertical bending to traverse a large step (Gart, Mitchel, Li, 2020, *JEB*). Here, we hypothesize that generalist snakes bend their body both vertically and laterally to traverse complex 3-D terrain. We tested corn snakes *Pantherophis guttatus* (N = 2 animals, n = 23 trials) traversing low-friction, rugged terrain comprising blocks of normally distributed heights. Despite the low friction, the animal traversed stably with little slip as if it were moving in a tube, with frequent changes in head direction. In addition, the animal tended to move on top of lower blocks, as if it were going through a valley in the rugged terrain. On these lower blocks, the body bent vertically to push backward against horizontal ridges to propel forward. Although lateral bending was occasionally used to push against the side of higher blocks, it was not sufficient to explain the observed motion. These observations supported our hypothesis. To better understand how the animal controls 3-D body bending to traverse, we are developing a sensorized terrain platform to measure distributed ground reaction forces and a sensorized snake robot as a physical model for systematic experiments (see other talk: Ramesh *et al.*, A sensorized robophysical model to study snake locomotion in complex 3-D terrain).

28-9 Fudge, DS*; Plachetzki, DC; McCord, CL; Winegard, TM; Fernholm, B; Gonzalez, CJ; Mincarone, MM; Chapman University, University of New Hampshire, Chapman University, California State University Dominguez Hills, Swedish Museum of Natural History, Universidade Federal do Rio de Janeiro; *fudge@chapman.edu*

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Description of four new species of hagfishes from the Galapagos Islands, Ecuador

Hagfishes are an ancient group of benthic marine craniates that are found in deep or cold waters around the world. In the Galápagos Islands, four species of hagfishes were known: *Eptatretus bobwisneri*, *E. grouseri*, *E. mccoskeri*, and *Rubicundus lakeside*. During recent expeditions to the Galápagos, six species of hagfishes were collected, including four undescribed species of the genera *Eptatretus* and *Myxine*. In this talk, I will provide a review of the eight species of hagfishes from the Galápagos Islands, with an emphasis on the four new species. Our species delineations were based on both morphological and molecular analyses. One of the new *Myxine* species described is remarkable as it is the only hagfish known to completely lack melanin-based pigments. A phylogenetic hypothesis based on molecular data suggests that Galápagos hagfishes, in contrast to terrestrial animals like Darwin's finches, arose from multiple independent colonisations of the islands from as many as five different ancestral lineages. The large number of endemic hagfishes in the geologically young Galápagos Islands suggests that there is much global hagfish diversity yet to be discovered.

64-2 Fuess, LE*; den Haan, S; Ling, F; Weber, J; Steinel, NC; Bolnick, DI; Texas State University, Central European University, Northwest A&F University, University of Wisconsin- Madison, University of Massachusetts Lowell , University of Connecticut; *lfuess@txstate.edu*

Immune gene expression covaries with gut microbiome composition in stickleback

Commensal microbial communities have immense effects on their vertebrate hosts, contributing to a number of physiological functions as well as host fitness. In particular, host immunity is strongly linked to microbiota composition through poorly understood bi-directional links. Gene expression may be a potential mediator of these links between microbial communities and host function. However few studies have investigated connections between microbiota composition and expression of host immune genes in complex systems. Here we leverage a large study of laboratory-raised fish from the species *Gasterosteus aculeatus* (three-spined

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stickleback) to document correlations between gene expression and microbiome composition. First, we examined correlations between microbiome alpha diversity and gene expression. Our results demonstrate robust positive associations between microbial alpha diversity and expression of host immunity. Next, we examined correlations between host gene expression and abundance of microbial taxa. We identified 15 microbial families that were highly correlated to host gene expression. These families were all tightly correlated to host expression of immune genes and processes, falling into one of three categories: those positively correlated, negatively correlated, and neutrally related to immune processes. Furthermore, we highlight several important immune processes that are commonly associated with abundance of these taxons, including both macrophage and B cell functions. Further functional characterization of microbial taxa will help disentangle the mechanisms of the correlations described here. In sum, our study supports prevailing hypotheses of intimate links between host immunity and gut microbiome composition.

S4-3 Full, RJ*; Estrada, M; Watson, L; Bhatti, HA; University of California, Berkeley, University of California, San Francisco; *rjfull@berkeley.edu*

i4's toward tomorrow program: Bioinspired design realized by creativity, collaboration, and connection

Our program's goal is to provide a STEM-enriched workforce with an early, inspirational, and interdisciplinary experience that fosters inclusive excellence. By seeking connections and joining a community, students envision a future where they can be *i*nvolved, *i*magine, *i*nvent, and *i*nnovate (i^4). Our program removes artificially created disciplinary boundaries to extend beyond STEM by including designers, social scientists, and entrepreneurs collaborating in diverse teams while using scientific discoveries to create inventions that lead to new careers, benefit society, and shape our future. We connect two recent revolutions by amplifying bioinspired design with the maker movement and its democratizing effects empowering anyone to innovate and change the world. By working in collaborative, interdisciplinary teams of diverse majors, pre- and post-assessment showed significant increases in students' 21st century skills that include

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interdisciplinary thinking, collaboration, science literacy and translation. We are disseminating our customizable, evidence-based program through a bioinspired design shared community that will energize students to participate in the discovery process where their diverse voices are necessary to invent the future.

5-1 Fullerton, JA*; Weesner, AT; Bentley, I; Kloepper, LN; Saint Mary's College; *lkloepper@saintmarys.edu*

Wingbeat synchronization in Mexican free-tailed bats (Tadarida brasiliensis)

Animals in nature move in groups often with often remarkable coordination including starling murmuration and fish schooling. Bats also exhibit coordinated group movement during foraging and navigation, and are especially interesting because they primarily navigate with echolocation. Additionally, recent work has suggested that bats have sensory hairs on their wings that aid in flight coordination. Bats have also been recorded to pair during flight in a "leader-follower" relationship based on their flight trajectories, but the kinematics behind the pairing is unknown. Motivated by prior observations, we investigated the flight dynamics for pairs of bats engaged in leader-follower relationships that appeared to have synchronized wingbeats. Mexican free-tailed bats (Tadarida brasiliensis) were recorded with a thermal imaging camera while they performed nightly emergences from a cave located on private land in Oklahoma. Bat pairs with observed synchronization were extracted for digital video analysis. Using anatomical landmarks digitized in the DLTdv8 MATLAB application, we quantified the flight trajectory, position, and wingbeat dynamics of bat pairs as they moved through the camera's field of view. We report on the degree of wingbeat synchrony and discuss the advantages such synchrony could provide during group flight.

S2-8 Furr, D; Ketchum, RN; Leach, WB; Ivanina, AV; Reitzel, AM*; University of North Carolina, Charlotte; *areitze2@uncc.edu*

Genetic and environmental correlates of physiology and gene expression for the eastern oyster in the southeastern United States

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Eastern oysters (*Crassostrea virginica*) have long been utilized as informative coastal organisms to determine mechanisms for acclimating and adapting to extreme environmental variation. These oysters are resilient to extensive abiotic (temperature, salinity, oxygen) and biotic (microbial and viral pathogens) variation, which can vary for oysters from different habitats and geographic locations. *C. virginica* is native to the southeastern United States and is routinely aquacultured, but little comparative data are available describing physiological and genetic variation for oysters in this geographic region. We will present the results from two sets of experiments aimed at understanding this variation. First, we compared genetic diversity and gene expression for oysters from four locations in North Carolina and Virginia to compare the innate immunity response to a pathogen (Vibrio) under normoxic and hypoxic conditions. Second, we used transcriptome-wide gene expression and physiological responses for intertidal and subtidal oysters from two locations in North Carolina to compare the influence of habitat and location on these phenotypes. Together, our results are important for understanding genetic variation and physiological plasticity in stress response for this commercially important oyster species.

45-9 Furze, ME*; Huggett, BA; Chamberlain, CJ; Wieringa, MM; Aubrecht, DM; Carbone, MS; Walker, JC; Xu, X; Czimczik, CI; Richardson, AD; Harvard University and Yale University, Bates College, Harvard University, Harvard University, Northern Arizona University , University of California,
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Junk in the trunk: can trees use carbohydrate reserves that are deep in the stem?

Carbohydrates play a key role in plant physiology and metabolism, yet we know little about their distribution within tree stems. This leaves open questions about whether carbohydrate reserves deep in the stem are available to support tree functions. To explore the availability of reserves, we measured the radial patterns of carbohydrates throughout the year in the stems of temperate trees with contrasting wood anatomy (ring-porous vs. diffuse-porous). We showed that carbohydrates were the most seasonally dynamic in the outermost stem segments for both ring-porous and diffuse-porous

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trees. However, while the seasonal fluctuation was dampened in deeper stem segments for ring-porous trees, it remained high for diffuse-porous trees. Our results suggest that while deeper stem reserves fluctuated across the seasons, the deepest reserves at the center of the stem were not used to support tree metabolism under normal environmental conditions.

S12-6 Fusani, L*; Janisch, J; Perinot, E; Quigley, C; University of Vienna, University of Veterinary Medicine,
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The making of an elaborate courtship display: acrobatics, choreographies, and the role of females

Among the most impressive features of manakins' courtship displays are their acrobatic jumps and flights. Neuromuscular and skeletal specializations are found in many species of these birds and they are typically functional to production of non-vocal sounds but also to performance of challenging motor displays. Detailed descriptions of the displays were published in the last two decades following advances in high-speed videography, although analysis of courtship focused mostly on the timing and sequence of display elements. In recent years, we were able to conduct detailed studies of the displays of the male golden-collared manakins (*Manacus vitellinus*) in relation to the presence of females and to the physical features of the displaying court. Here we will review these latter developments that reveal novel, previously unknown aspects of manakins' courtship. We will illustrate how females participate in shaping male displays and actively 'test' courting males' skills. In addition, we will show how males can rapidly adjust their choreographies following environmental events that disrupt the displaying court, in a manner strongly suggesting the involvement of motor learning in the making of the display.

S12-3 Fuxjager, MJ; Brown University; *matthew_fuxjager@brown.edu*

Physiological basis of display evolution in the golden-collared manakin

Sexual selection produces a variety of extraordinary traits used to court mates and compete with rivals in reproductive contexts. This process is often predicated on concomitant changes to an organism's

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physiology, which in turn support the emergence of extreme or complex morphology and/or behavior. Yet despite widespread recognition of the important connections between sexual selection and physiology, these links are not often studied. My research program helps fill this gap by investigating manakin birds, given that many species in this family perform extraordinary courtship displays that often require specialized motor capabilities. In particular, I focus on golden-collared manakins (*Manacus vitellinus*), as males of this species perform an acrobatic sexual display that involves rapid gestural movements. My work shows that modifications to this bird's androgenic hormone system within the skeletal musculature reshape performance abilities in a way that allows for behavioral innovation in response to sexual selection. This work is discussed, with an emphasis on the ability of hormones to influence performance tradeoffs that impact behavioral output. Overall, my results shed light on the role hormone systems play in behavioral evolution in response to sexual selection.

22-9 Gabler-Smith, MK*; Wainwright, DK; Wong, GA; Lauder, GV; Harvard University, Cambridge, MA, Yale University, New Haven, CT; *mollygablersmith@gmail.com*

Shark dermal denticles: novel patterns on branchial skin

Shark skin is covered in dermal denticles - tooth-like structures consisting of enameloid and dentine. There are many proposed functions of denticles, including abrasion reduction, protection against parasites, drag reduction and increased lift during swimming. Previous studies have shown differences in denticle morphology within and across different regions of sharks, including extreme morphological differences within the skin covering the branchial pouches, a region termed "branchial skin". We used gel-based profilometry to quantify differences in denticle morphology and surface topography of branchial skin denticles among 13 species of sharks to better understand the surface structure of this region. We show that 1) branchial skin denticles differ across shark species and 2) denticles on the leading edge of the branchial skin have different morphology and surface topography compared to denticles on the trailing edge. Across all species studied, there were significant differences in denticle length (P=.01) and width (P=.002), with shorter and wider leading edge denticles compared to

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trailing edge denticles. Skewness was also higher in leading edge denticles (*P*=.009), though most values were still negative, indicating more valleys than peaks. Overall, leading edge denticles are rounder than trailing edge denticles in all of the species studied. These data suggest two hypotheses: 1) rounder leading edge denticles protect the previous gill flap from abrasion during respiration and 2) denticle morphology might affect flow exiting branchial pouches after passing over the gills. Future studies will focus on determining the relationship between denticle morphology and water flow by visualizing fluid motion over branchial denticles during *in vivo* respiration.

S1-12 Gabor, CR*; Miner, K; Forsburg, Z; Texas State University, San Marcos; *gabor@txstate.edu*

ALAN in freshwater vertebrates: physiology, growth, and behavioral perspectives

Anthropogenic disturbances through land use conversion contribute to population extinctions and biodiversity loss. These modifications are associated with shifts in water quality, water flow, and light pollution. Artificial light at night (ALAN) alters the natural light and dark cycle in ecosystems. Light plays a key role in the ecology of organisms as a source of energy and information, a regulator of circadian rhythms, and a cue for communication, navigation, and orientation. Owing to urbanization, 40% of human populations are living in areas that are continually illuminated due to ALAN. Additionally, 50% of the human population lives within 3 km of aquatic ecosystems, making aquatic areas the most impacted by anthropogenic disturbances, such as ALAN. While ALAN is widespread, the consequences of ALAN have not been well documented, especially in freshwater species. Here we review the literature that examines consequences of ALAN on physiology, growth, and behavior in fish and amphibians. We focus on recent mechanistic studies using common species of tadpoles and fish along with an endangered species of salamander. We also explore the potential for populations to respond to selection from ALAN from the perspective of repeatability of the glucocorticoid response to ALAN exposure. We find that ALAN affects glucocorticoid hormones, growth, melatonin, and glucose levels, all of which can influence

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the fitness of aquatic organisms and may further drive biodiversity loss.

15-5 Gábor, A*; Kaszás, N; Faragó, T; Pérez Fraga, P; Lovas, M; Andics, A; Department of Ethology, ELTE, Hungary; *annagabor33@gmail.com*

Acoustics of dogs' interspecific voice discrimination ability

Voices are prominent stimuli in the auditory environment due to the wide variety of ecologically relevant information they code in their acoustic structure, including vocalizer identity cues. Acoustics of voice-based individual recognition is well-described in intraspecific-, but unknown in interspecific contexts. Dogs, for whom the identification of humans became crucial during domestication, are suitable subjects of such investigations. In a behavioural test, dogs had to find their hiding owner based on vocal cues in two-way choice tasks. Stimuli were pre-recorded neutral speech sentences from the owner and a set of control persons played through loudspeakers (placed near the hiding persons) from behind two opaque screens. The effect of speakers' acoustic distance along a set of dimensions on choosing success, choosing latency and looking time was investigated. Dogs chose their owner's voice significantly more often than control persons' voices (82%) and acoustic distance of speakers did not affect their choosing success, which suggests that dogs can confidently identify their owner's voice. Fundamental frequency-related (F0 mean, gender difference of speakers) and noisiness parameters (entropy, jitter) affected either choosing latency or looking time which, however, indicate that the shorter the acoustic distance between speakers, the harder the decision. According to these results, interspecific voice recognition in dogs is based on similar acoustic parameters as intraspecific voice recognition in both humans and in various canine species. This novel experimental design is applicable to further explore dogs' interspecific voice recognition ability by artificially modifying the voices.

93-1 Gage, S*; Aiello, BA; Sharma, V; Sprayberry, J; Sponberg, S; Georgia Tech , Muhlenburg College; *sgage7@gatech.edu*

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Does an ecologically-relevant odor influence visual motion selectivity in the hawkmoth nerve cord?

The behavioral context of an animal can modulate visual processing. First observed in primates, and recently in flies and mice, attention and locomotion modify visual neuron tuning curves by increasing spike rates and shifting curves to higher frequencies. These changes may enable animals to better process rapidly changing visual scenes associated with motion compared to quiescence. We wondered whether sensory context, specifically the addition of an ecologically-relevant odor, could similarly affect how neurons respond to visual motion. We considered the crepuscular hawkmoth, *Manduca sexta*; which relies on both vision and olfaction to locate and forage from flowers, a process that transitions from flight navigation to hover feeding. We hypothesized that the tuning curve of wide-field motion (WFM) units would increase overall firing rate and shift towards higher frequencies; and that responsiveness to oscillating flowers would also increase with odor. To test these ideas, we recorded from ventral nerve cord neurons downstream of sensory integration centers in the brain. Using a multi-channel electrode, we established responses to WFM and flower stimuli, followed by a floral odor known to elicit innate odor responses. Odor enhanced the firing rate of WFM responsive units and shifted the peak of the tuning curve 1-2 Hz higher. Some direction-sensitive units also began to respond in the opposing direction. Flower-responsive units showed increased firing rates. In some units, however, odor inhibited responses to both types of visual motion. This change in gain and selectivity may suggest that odor functions as a "fine tuner" during navigation and hovering. Odor may refine visual tuning for close flower tracking and other rapidly moving, near-field objects during foraging.

BSP-4-7 Gainett, G*; Sharma, PP; University of Wisconsin-Madison; *guilherme.gainett@wisc.edu*

How do arachnids make antennae out of legs? An evo-devo approach in whip spiders (Amblypygi)

The recent discovery of a whole genome duplication (WGD) event in arachnids with book lungs (Arachnopulmonata) posits them as ideal research organisms to study the implications of this process in the

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evolution of morphology. A fascinating phenomenon that has independently evolved in different arachnid orders is the "antennification" of a walking leg pair to serve a sensory function, a convergence with the antenna of mandibulates (e.g., insects, centipedes). Arguably the most complex antenniform legs in arachnids occur in the arachnopulmonate order Amblypygi (whip spiders) but it is unknown if they retain ohnologs from the inferred WGD event, and which genetic factors specify the fate of antenniform legs. To investigate the incidence of systemic gene duplications in this order, we assembled the first embryonic transcriptomic resources for three whip spider species. We show evidence that Amblypygi retain two complete Hox clusters and duplicates of numerous developmental patterning genes. We then established an evo-devo tool kit for the species *Phrynus marginemaculatus* and showed that expression of leg gap gene paralogs (*Distal-less*, *dachshund* and *homothorax*) support a shared WGD across Arachnopulmonata. Next, we conducted differential gene expression analysis between antenniform legs and walking legs in embryonic stages before and after leg specification, revealing candidate genes with verifiable expression patterns via in situ hybridization. In particular, we found evidence that a Hox gene paralog may be involved in the early specification of the sensory leg, a hypothesis amenable to testing with the functional tools we have recently established for this species.

31-4 Galbraith, E*; Santamaria, C; Hoffman, M; Gainsbury, A; University of South Florida, St. Petersburg, FL, University of South Florida, Sarasota, FL, Orianne Center for Indigo Conservation, Eustis, FL; *galbraith.elf@outlook.com*

Environmental DNA detection method from soil samples for Eastern Indigo snakes (Drymarchon couperi)

Environmental DNA (eDNA) is DNA shed by organisms into the soil or water with which they interact. It offers an opportunity to survey wildlife non-invasively, which is especially useful for endangered and threatened species. The Eastern Indigo snake (*Drymarchon couperi*) is a Federally threatened snake species with historic habitat in the dry forests of the southeast United States. We developed a novel protocol for Indigo snake presence detection using eDNA from soil samples. These soil samples were obtained from

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outdoor snake enclosures from the Orianne Center for Indigo Conservation in Eustis, FL and from a captive snake release site in Conecuh National Forest in Alabama. Ten soil samples from areas with confirmed snake activity were used to test eDNA extraction from soil using Longmire's buffer and the Zymo Quick-DNA Miniprep Plus Kit. We successfully detected snake presence with DNA from genes NADH dehydrogenase 4 (ND4) and cytochrome b (CYTB). This method was then applied to the field at Archbold Biological Station, showing that this protocol can be used as an inexpensive, simple, non-invasive technique of surveying the threatened indigo snake. The broader implication of this novel methodology is its application to other elusive endangered and threatened species with which presence can be obtained from eDNA soil samples.

S9-11 Gall, MD*; Baugh, AT; Lucas, JR; Bee, MA; Vassar College, Swarthmore College, Purdue University, University of Minnesota; *megall@vassar.edu*

Social communication across reproductive boundaries: hormones and the auditory periphery

Most animals experience reproductive transitions in their lives; for instance, reaching reproductive maturity or cycling in and out of breeding condition. Some reproductive transitions are abrupt, while others are more gradual. In most cases, changes in communication between the sexes follows the time course of these reproductive transitions and is typically thought to be coordinated by steroid hormones. We know a great deal about hormonal control of communication behaviors in birds and frogs, as well as the central neural control of these behaviors, as there have been foundational studies in hormones and behavior, as well as neuroethology. There has also been a significant interest in the effects of steroid hormones on central nervous system structures that control both the production and reception of communication signals associated with reproductive behaviors. However, peripheral sensory structures have typically received less attention, although there has been growing interest in recent years. It is becoming clear that the function of peripheral sensory structures plays an important role in reproductive communication, is plastic across reproductive conditions, and, in some cases, may be mediated by steroid hormones. In this talk, I will discuss our current understanding of

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the role of peripheral auditory structures in reproductive communication in birds and frogs, the plasticity of the peripheral auditory system, and the role of steroid hormones in mediating the effects of the peripheral auditory system on reproductive communication.

29-2 Gallagher, KA*; Caira, JN; Wegrzyn, J; Christian Brothers University, Memphis, TN, University of Connecticut, Storrs, CT; *kgallag2@cbu.edu*

Morphological and genomic evolution of pelagic thresher shark tapeworms

This study examines the evolution of *Litobothrium aenigmaticum*, a bizarre tapeworm that parasitizes pelagic thresher sharks in Taiwan and Mexico. Although this species nests robustly within the genus *Litobothrium*, it lacks all the characteristics typically displayed by this group. Furthermore, transmission electron microscopy has revealed that the attachment organ of this worm contains 11 unique cell types that have not been seen in any other tapeworm species. Our current study investigates the mechanisms that may have allowed for the evolution of this unusual morphology using comparative genomics and transcriptomics. To this end, we have assembled and annotated the genome of three litobothriidean species: *L. aenigmaticum*, its sister taxa *L. daileyi*, and the more distantly related *L. amplifica*. The genomes for these species range in size from 300-320 Mb with approximately 19,045-27,953 genes. Gene family evolution is currently being assessed with the program CAFE. Transcriptomes have also been generated for the three litobothriidean species. Differential gene expression analyses do not show many differences in gene expression, however, there appear to be some modest differences in the expression levels of genes associated with the immune system and anatomical structure. Overall, our current results indicate that the change in morphology may be due more to genomic change than differences in gene expression.

5-3 Gallagher, JH*; Zonana, DM; Broder, ED; Tinghitella, RM; University of Denver, Denver, Colorado, Saint Ambrose University, Davenport, Iowa; *jay.gallagher@du.edu*

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The origin and rapid spread of evolutionary novelty: characterizing song and wing variation in two newly discovered cricket morphs

The opportunity to observe and study the evolution of a novel trait in real time is exceptionally rare. The recent appearance and rapid spread of two new morphs with different mating songs, purring and rattling (introduced in this study), in Hawaiian populations of the Pacific field cricket (Teleogryllus oceanicus) provides a unique chance to investigate this phenomenon. Songs of purring males have been shown to be attractive to female crickets and less detectable to a deadly, acoustically orienting parasitoid fly than songs of ancestral males. Purring males have now been found in five different populations throughout Hawai'i. The most recently discovered phenotype, rattling, has become widespread in one surveyed population. In order to understand how selection may shape these new signals, we characterized the initial variation in purring and rattling songs among and within populations at "time zero." For purring, rattling, and ancestral males, we recorded calling and courtship songs from six long-studied sites and analyzed ten sound characteristics. We found differences in purring among populations for both calling and, to a greater extent, courtship songs. We also found that purring, rattling, and ancestral songs are spectrally distinct from one another. Crickets produce songs using specialized structures on their wings—however, it is unclear how, or even if, these well-known structures affect song characteristics in purring and rattling. Using standard landmarking techniques, we compared the wing morphology of males of different phenotypes and populations. This work continues to illuminate the mystery of how novel signals arise and spread through populations.

34-7 Gallardo, CR*; Stewart, JR; Bidwell, JR; East Tennessee State University; *gallardoc@etsu.edu*

Oxygen consumption during embryonic development in the oviparous snake, Pantherophis guttatus

In the amniotic egg of oviparous reptiles, most sources of energy required for embryonic development must be available within the egg, excluding oxygen and water, which are required from the environment. Variation in the metabolic patterns among different

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species of embryonic birds has been well described. These studies have recognized two patterns of oxygen consumption during development: a sigmoidal curve and a linear relationship between metabolism and incubation time. The sigmoidal curve is reported in most other species of reptiles, excluding snakes. Snakes are underrepresented in this type of research, although some studies have indicated an exponential curve for metabolic rate during development. Other members of Squamata do not exhibit this pattern, making this a potentially derived state. The aim of this study was to generate an oxygen consumption curve for the corn snake, *Pantherophis guttatus*, during development to test the hypothesis that embryos will exhibit an exponential increase in oxygen consumption over time. Oviposited eggs were placed in chambers for 24-hour periods and percent oxygen was recorded throughout development. Embryos were staged and the carcass and yolk were weighed separately. Results indicated a steady incline in oxygen consumption during the earlier stages of development, with a rapid increase as hatching approached. Our data support the hypothesis that the developmental pattern of oxygen consumption in snakes differs from other squamates.

32-1 Gallery, DN*; Green, ML; Kuffner, IB; Lenz, EA; Toth, LT; U.S. Geological Survey, University of South Florida, University of Hawai'i at Manoa; *dgallery@utexas.edu*

Genetic diversity of the mustard hill coral (Porites astreoides) along the Florida Keys Reef Tract

Increased stressors on coral reefs in recent decades have led to a decline in coral populations throughout the Florida Keys Reef Tract (FKRT). In contrast, the relative abundance of *Porites astreoides* has increased throughout the western Atlantic due to its "weedy" life history strategy. Compared to reef-building species, *P. astreoides* is relatively resistant to some environmental stressors and, due to its mixed reproductive strategies, its populations often recover relatively quickly after disturbances. Whether *P. astreoides* will continue to be a "winner" on western Atlantic reefs, however, will depend on its ability to acclimatize and/or adapt to changing environments in the future. The potential for high rates of selfing and other asexual reproductive modes observed in some studies suggest that many

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colonies of *P. astreoides* may be clones rather than genetically distinct individuals, which could limit the species' capacity for adaption. Population genetics can provide clues for understanding regional species ecology and diversity and help identify how populations may change in the future. In this study, we determined the genetic diversity of 40 *P. astreoides* samples at four locations along the FKRT using previously designed microsatellite markers. Our results suggest that clones were relatively rare at our sites, and the FKRT most likely contains a single, well-mixed genetic population of *P. astreoides*, with high levels of gene flow in the region. This suggests that *P. astreoides* will likely continue to be resilient to future stressors while the larger causes of anthropogenic stressors are addressed.

98-11 Gálvez-López, E*; Cox, PG; Dept. Archaeology, University of York, York, UK; *eloy.galvezlopez@york.ac.uk*

Cranial shape variation in minks: Separating two highly similar species

European and American minks (*Mustela lutreola* and *Neovison vison*, respectively) are very similar in their ecology, behavior and morphology. However, the American mink is a generalist predator and seems to adapt better to anthropogenic effects, allowing it to outcompete the European mink in areas where it has been introduced, threatening the survival of the native species. To assess whether differences in the masticatory apparatus allow American mink to exploit a wider range of food items than European mink, we analyzed shape variation in the cranium of both species using 3D GMM. A set of 37 landmarks and 107 semilandmarks was digitized on each specimen and, after superimposition, shape variation was explored with Principal Component Analysis. Differences in size and shape between and within species were assessed with Procrustes ANOVA. European minks were shown to have a relatively smaller face with a shorter and wider palate, a slightly longer and narrower neurocranium, and broader and less curved zygomatic arches. Covariation between size and shape was also noted, with small specimens with globous neurocrania and large specimens with marked airorhynchy and well-developed sagittal and nuchal crests. In bigger specimens the face and palate expand (to accomodate bigger teeth), as do the origins of the masticatory muscles. Significant

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differences between species were found in cranial shape, but not in size. Within species, males and females were significantly different both in size and shape. Overall, differences in cranial shape between species suggest that American mink have stronger masticatory muscles (i.e., higher bite forces) and a wider gape than European mink, which would increase the range of their diet (bigger prey, tougher shells) and also make them more efficient at killing small prey.

89-5 Gangloff, EJ*; Bodensteiner, BL; Kouyoumdjian, L; Muñoz, MM; Aubret, F; Ohio Wesleyan University, Yale University, Station d'Ecologie Theorique et Experimentale du CNRS, Station d'Ecologie Theorique et Experimentale du CNRS; *ejgangloff@owu.edu*

Adaptation and plasticity in the multivariate thermal phenotype of common wall lizards

Temperature and oxygen availability interact to shape nearly every aspect of ectotherm biology, from blood biochemistry to metabolic capacity to whole-organism performance. To test the relative roles of local adaptation and within-individual plasticity in response to reduced oxygen availability in shaping the multivariate thermal and metabolic phenotype, we performed a transplant experiment with the upslope-colonizing common wall lizard (*Podarcis muralis*). First, we measured nine aspects of thermal physiology and aerobic capacity in lizards from replicate low elevation (400 m above sea level) and high-elevation (1700 m ASL) populations at their native elevation. We then transplanted half of each group to extreme high elevation (2900 m ASL), where oxygen availability is reduced by ~25% relative to low elevation sites. After three weeks of acclimation, we again measured these traits and identified multiple phenotypic shifts. Traits relating to long-term aerobic capacity, including blood haemoglobin concentration and running endurance capacity, demonstrated acclimation to both captivity and reduced oxygen availability. Upper and lower critical thermal limits, resting metabolic rate, and maximal metabolic rate did not demonstrate a strong plastic response, but did segregate between lizards from low- and high-elevation populations, suggesting these traits may be locally adapted. By identifying axes of covarying traits that may shift via within-individual plasticity or as a result of selection,

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we can better characterize potential restraints on organismal response to novel thermal and oxygen environments.

105-1 Ganley, A*; Bartol, I; Old Dominion University; *agan1001@odu.edu*

Maneuverability of hatchling Sepia officinalis

Maneuvering is essential for predator avoidance, prey capture, and habitat exploration, yet biomechanical research on the turning capabilities of many swimming animals is limited, especially during early ontogeny. For this study, we focused on understanding turning performance in hatchling cuttlefish *Sepia officinalis*, which has complex locomotory systems with multiple control surfaces and propulsors (jet and fins) that may be used independently or in concert. The cuttlefish (0 -14 days old, 5-8 mm mantle length) were placed in viewing chambers, and swimming behaviors and wake flows were recorded using high-speed videography and particle image velocimetry (PIV), respectively. The cuttlefish exhibited a range of turning behaviors, including tight turns with significant body and jet flow interactions and broad turns with greater spatial and temporal body/jet flow separation. Jet propulsion outweighed fin contributions in most turns, with vortex rings being prominent features of jet wakes, and cuttlefish demonstrated both arms-first and tail-first turning. Our results suggest cuttlefish display a broad repertoire of turning capabilities even during early ontogenetic development.

S10-9 Garayev, K*; Murphy, D; University of South Florida; *kgarayev@usf.edu*

Vortex interactions among pleopod pairs in a mantis shrimp swimming at high advance ratios

Metachronal rowing is a ubiquitous locomotion method among organisms with multiple in-line appendages in which posterior appendages start the stroke and are then followed by more anterior neighbors. Organisms relying on this swimming technique range in size from ciliates to lobsters. The leg kinematics of metachronally swimming organisms have been previously reported for a wide range of swimming speeds. However, the appendage hydrodynamics of freely swimming animals have only been measured for hovering or slowly

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swimming animals. Here we present time-resolved 2D PIV measurements of the flow generated by a swimming mantis shrimp (*Odontodactylus scyllarus*) filmed at up to 1000 Hz using a near-infrared laser. Flow field measurements are acquired in sagittal, near-frontal, and transverse planes on an animal with body and pleopod lengths of 114 mm and 15 mm, respectively. Pleopod kinematics also are measured from the sagittal recordings. The mantis shrimp swims at speeds of 0.2-1.9 m/s by beating its pleopods at 3.6-12.5 Hz, which correspond to advance ratios of 1.1-1.5. Measurements in the sagittal plane show that each stroking pleopod pair creates a backwards-moving vortex which evades destruction by the recovery strokes of the other pleopod pairs. The vortex created by the anteriormost pleopod pair is the strongest, and owing to the high advance ratio, the posteriormost pleopod pair lies above this vortex and sweeps into it during its power stroke. As a result, the strength of this vortex increases, an interaction which may increase swimming speed or efficiency. Finally, flow measurements in the near-frontal plane show a pulsed, backward-directed jet accompanied by counter-rotating vortices resembling a reverse von Karman vortex street in the animal's wake.

63-5 Garcia, M*; Fotinos, E; Steffenson, M; St. Edward's University; *mgarci55@stedwards.edu*

Refining assay recipes to measure immunological responses

Immunology is the study of how organisms protect themselves against pathogens. The way the host's body responds to pathogens is by using specialized cells and proteins to attack invaders, collectively called the immune system. Vertebrate immunology is an extensively researched area of biology; however, the innate immune response of invertebrates is still not well understood. For example, it is unclear if the cost of activating an immune response differs among species with conserved immune pathways, and therefore if the similar colorimetric immune assay protocols can be utilized across taxonomic groups of invertebrates to produce similar results. The two species studied in this project are *Tigrosa helluo* (a wolf spider) and *Apis mellifera ligustica* (the Italian honeybee). Because both species differ biologically, the same assay recipe may not be well-optimized for both organisms. This project aims to develop optimized assay recipes specific to each species

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for enzymes used with invertebrates when mounting an immune response including prophenoloxidase, and the antioxidants peroxidase and catalase. Once the assays have been optimized it is hypothesized that the spiders will have lower levels of enzyme activity proportional to body size when compared to bees. Because bees have a more social lifestyle, one can infer that their innate immune system is constantly being utilized due to community transmission of pathogens. In comparison, cursorial spiders primarily live a solitary lifestyle, and thus are predicted to have a lower frequency of immune challenges that would consequently increase immune enzyme activity.

60-5 Gardner, SA*; Campbell, P; University of California, Riverside; *sgard014@ucr.edu*

Defining the origin of the prenatal gut microbiome in the house mouse

The developmental environment, including the microbiome (the community of symbiotic microbes that regulates diverse host processes), can strongly influence offspring phenotypes. In mammals, the microbiome is historically thought to establish in the postnatal period after exposure to microbiota in the maternal vaginal tract. However, recent evidence in mice suggests that the placenta is inoculated with microbes originating from the maternal oral cavity and vaginal tract, and that microbes are present in the embryonic gut by late gestation (embryonic day 17). This prenatal inoculation is thought to promote the development of the mucosal immune system in offspring. To determine the source of embryonic gut seeding in the house mouse (*Mus musculus domesticus*) at embryonic day 17, we collected tissue samples (n = 5 litters) from the placenta and embryonic gut, as well as a suite of maternal samples including the oral cavity, blood, gut, and vaginal tract. Microbial DNA was extracted from each sample and sequenced (V4 region of the 16S rRNA gene); sequence data were processed in Qiime2. Path analysis was used to compare the fit of alternative hypotheses for relationships between embryonic gut microbiota and candidate maternal sources. Future work will address when the prenatal microbiome is initially acquired and how this coincides with microbial shifts in maternal tissues over the course of pregnancy.

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42-10 Gardner, S*; Kepas, M; Simons, C; Horne, LM; Savitzky, A; Mendonça, M; Auburn University, Utah State University, University of Texas at El Paso; *stg0015@auburn.edu*

Differences in morphology and parotoid gland secretion (composition and release) of introduced cane toads (Rhinella marina) from established populations in Florida, USA

Cane toads are invasive in several locations throughout the world. We collected cane toads from populations spanning the invasion range in FL to assess morphological changes to parotoid glands and secretion likelihood, to determine how establishment northward has affected these parameters. We also collected secretion samples from individuals occurring in representative southern and northern populations and compared toxicity and the effects of increasing epinephrine doses on the likelihood of poison secretion in lab-acclimated toads. Residual body indices increased with increasing latitude, and parotoid gland size increased with increasing toad size. We found no effect of latitude on gland size or toad size, but secretion likelihood increased with increasing latitude. Marinobufagenin concentrations in cane toad secretions were not different between populations. Lab-acclimated cane toads were more likely to secrete poison with increasing epinephrine dose, although there was no difference between south and north population individuals. Quantities of epinephrine released upon disturbance in the field were likely responsible for secretion increasing with latitude.

10-1 Garner, AM*; Wilson, MC; Wright, C; Russell, AP; Dhinojwala, A; Niewiarowski, PH; University of Akron, University of Calgary; *amg149@uakron.edu*

Ecomorphological correlates of the adhesive setae and setal fields of Jamaican anoles

Caribbean *Anolis* lizards are considered model organisms for the study of adaptive radiation and ecomorphology. Distantly related and geographically isolated species of *Anolis* demonstrate convergence of morphological features and functional capabilities that covary with structural habitat use. Adhesive performance, for example, is positively correlated with perch height, even when

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macromorphological variables, such as subdigital pad area and body size, are taken into consideration. Subdigital pad area, however, does not explain 100% of the variation in adhesive performance, suggesting the presence of other explanatory factors. Subdigital microstructure is one obvious candidate, but few studies have examined it, and even fewer in an ecomorphological framework. Here we examine the setal morphology (e.g., setal length, diameter, and density) and setal field configuration (i.e., how setal morphology varies along the proximodistal axis of the pad) of five species of Jamaican anoles, representing four of six 'ecomorph' categories. Ecomorphological differences in adhesive microstructure have long been suggested in anoles, yet our study is the first to empirically examine this. Our findings enhance our understanding of the evolution of the subdigital adhesive apparatus of not only anoles, but all adhesive pad-bearing squamates.

4-2 Garner, AM*; Pamfilie, AM; Dhinojwala, A; Niewiarowski, PH; University of Akron; *amg149@uakron.edu*

Tokay geckos (Gekkonidae: Gekko gecko) preferentially use substrates that elicit maximal adhesive performance

Gecko substrate use is likely influenced by adhesive performance, yet this has not been demonstrated empirically. For the first time, we examined the substrate use, adhesive performance, and vertical clinging behaviour of *Gekko gecko* in captivity to investigate whether adhesive performance influences patterns of substrate use. We found that geckos were observed significantly more often than expected by chance on the substrate that elicited maximal adhesive performance. Our work here provides some of the first data establishing connections between adhesive performance and patterns of substrate use in captivity, suggesting the hypothesis that substrate preferences of free-ranging geckos should be correlated with adhesive performance.

55-4 Gartner, SM*; Evans, K; Westneat, MW; University of Chicago, Rice University; *sgartner@uchicago.edu*

morphometrics and biomechanics of the three-dimensional four-bar linkage systems in wrasses (family: Labridae)

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The evolutionary history of feeding biology within fishes involves the diversification of skull mechanisms for suction feeding, biting mechanics, and food processing. Within reef-associated wrasses (family Labridae), the spectrum of feeding behaviors includes the extremes of suction and biting specialists. This diversity alongside a well-resolved phylogeny allows for rigorous phylogenetic comparative methods to be used to understand the evolutionary drivers of structural and functional changes in feeding. Using 3D geometric morphometrics, we investigated the planarity and shape of the three four-bar linkage systems within wrasses (oral jaws, opercular, and hyoid) across 155 species. We predicted that these three major 4-bar linkages would show different levels of variation and three-dimensionality, with the anterior jaws linkage hypothesized to be more planar, yet exhibit more variation, than the other linkages due to its pivotal role in prey capture. We found the oral jaws and the hyoid linkage to be more aligned in a 2D plane compared to the opercular linkage which extends more laterally. For the oral jaws linkage system, PC1 and PC2 mainly captured variation in the location of the coronoid process. PC1 and PC2 of the phylomorphospace for the opercular linkage system mainly captured the lateral position of the interopercle-opercle joint. The phylomorphospace for the hyoid linkage mainly captured the variation in location of the interhyal in relation to the post-temporal-neurocranial joint. We show that the three linkage systems vary in important geometric proportions effecting the transmission of force and motion during feeding. This study helps to understand the influence of these four-bar linkage systems on the overall cranial morphology of the skull within wrasses. NSF DEB-1541547

101-6 Garzella, CS*; Dillon, ME; University of Wyoming, Univeristy of Wyoming; *craig.garzella@uwyo.edu*

Ground truthing microclimate models: Can we use large-scale macroclimate to predict temperatures organisms experience in the soil?

Climate change research relies largely on macroscale climate estimates to infer past and predict future effects on organisms. But organisms function at smaller scales and the microclimates they experience are likely far more important in determining effects of

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and responses to climate change. Empirical characterization of microclimates is rare and unrealistic across large spatial scales (at least in the near term). Mechanistic models have emerged as a promising alternative approach to predicting microclimates by incorporating macroclimatic measurements into biophysical models of heat and mass exchange. The broad utility of these models depends on verifying that they work: that is, testing whether predicted microclimates match measured ones. We compared high frequency measurements of soil temperatures (0-50 cm depth) at 287 sites across North America with temperatures predicted by NicheMapR, a biophysical model that incorporates estimates of air temperature and pressure, wind speed, humidity, solar radiation, and rainfall to predict soil temperatures (to 50 cm depth). Model predictions closely matched measured soil temperatures only in low elevation, flat areas with minimal seasonal temperature variation (61% of sites). For areas at higher elevations, with more complex topography, and with higher seasonal fluctuations in temperature, model predictions were often far from measured temperatures (as much as 10 ° C cooler in summer months). These and other mechanistic models will be most useful only when they accurately characterize microclimates experienced by organisms. Better predictions of soil temperature in diverse locations may require consideration of additional factors, including slope steepness, cold air pooling, and cloud cover.

S1-2 Gaston, KJ*; Ackermann, S; University of Exeter, Environment & Sustainability Institute; *k.j.gaston@exeter.ac.uk*

Ecological impacts of horizontal artificial nighttime light emissions

The erosion of the natural nighttime by the introduction of artificial lighting is globally widespread and increasing rapidly. There is now substantial evidence of the biological impacts that this change is having on a wide array of biological phenomena, from gene expression to ecosystem functioning, and from individual organisms to communities. Attention to date has focussed almost exclusively on impacts that arise from the downward emissions that are experienced by organisms in the vicinity of artificial light sources (such as streetlights). However, when uninterrupted, or reflected at shallow angles, artificial light can carry

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horizontally over long distances from sources at biologically readily detectable levels. In some instances this horizontal transmission is unintentional, in others it is not (e.g. vehicle headlights). At distance, it may manifest as a point emission through to more of a lit horizon. In this presentation we will consider the nature, extent and ecological implications of horizontal artificial light emissions. In particular, we will focus on how the challenges and effects of these emissions differ from those that are more commonly considered.

BSP-7-1 Gatch, L*; Stein, L; University of Oklahoma; *laura.gatch-1@ou.edu*

Venom and social behavior: using spiders to evaluate the evolution of sociality under high risk conditions

Risks of sociality, including competition and conspecific aggression, are particularly pronounced in venomous invertebrates such as arachnids. Spiders show a wide range of sociality, with differing levels of cannibalism and other types of social aggression. In order to interact safely and have the greatest chance of surviving interactions with conspecifics, spiders have to learn how to assess and respond to risk. One of the major ways risk assessment is studied in spiders is via venom metering, in which spiders choose how much venom to utilize based on prey and predator characteristics. However, while venom metering in response to prey acquisition and predator defense is well-studied, less is known about the use of venom in conspecific interactions. Therefore, spiders are poised to be an excellent system for understanding how venom use relates to the evolution of social behavior and, in return, whether social behavior influences venom use and evolution. Given that successful responses to risk are vital for maintaining sociality, comparative analysis of spider taxa in which venom metering and sociality vary can provide valuable insights into the evolution and maintenance of social behavior under fluctuating levels of risk.

BSP-4-3 Gavazzi, LM*; Kjosness, KM; Reno, PL; Kent State University and NEOMED, Philadelphia College of Osteopathic Medicine; *lgavazzi@neomed.edu*

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Pisiform reduction in hominoids and sloths: phenotypic convergence through developmental diversity

The typical mammalian wrist includes an elongated pisiform located between the triquetral and ulna that is formed from two ossification centers and an associated growth plate. Great apes are unusual in that the pisiform is shifted distally to articulate solely with the palmar surface of the triquetral. Humans and orangutans have also undergone pisiform reduction. In orangutans, this occurs through reduced growth preserving the secondary center, while humans have lost the primary center of ossification and growth plate entirely. Two-toed sloths, three-toed sloths, and giant anteaters (Xenarthra) have also distally shifted the pisiform to the palmar surface of the triquetral. The pisiforms of two- and three-toed sloths are also reduced similarly to humans. Using museum skeletal collections, we confirm the pisiform articulation and morphology in both families of sloths. We conducted a photographic and uCT analysis of an ontogenetic Xenarthran sample to determine the mechanisms of pisiform reduction in sloths compared to humans and orangutans. Giant anteater pisiforms follow the typical mammalian pattern of an elongate pisiform forming from two ossification centers. Both families of extant sloth form primary pisiform ossification centers, but we found no evidence of secondary ossification in either group. Instead, juvenile sloth pisiforms display an irregular subchondral surface suggesting an obliterated growth plate that allows the primary center of ossification to invade the secondary center directly. Our results further highlight the diversity of developmental pathways that can be utilized to achieve similar skeletal morphologies.

97-7 Geldof, DL*; Summers, AP; Cohen, KE; University of Washington, Friday Harbor Labs; *daniel.l.geldof@gmail.com*

An overview and definition of cirri in fishes

Abstract: Soft appendages are common in fishes, particularly on the head and along the lateral line. Excluding modified fin rays, these appendages are generally classified as barbels or cirri. Though barbels are mainly associated with Siluriformes, they have evolved in several lineages of fishes. The structure and uses of barbels have been explored, and here we document variation in morphology of cirri. We surveyed eight species of fishes, seven with cirri, and

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one with barbels (an agonid), to better characterize the differences between the two morphologies. We used histology and scanning electron microscopy and found that cirri in *Blepsias* have taste buds, and share near-identical internal structure to agonid appendages. As the functions of barbels and cirri are highly variable, structure is a better way to differentiate them. Siluriform barbels share an intrinsic musculature which cirri lack. We propose to define a cirrus as any soft appendage with a fibrous core and no intrinsic musculature, while a barbel has intrinsic musculature. Since agonid appendages lack musculature they are more properly called cirri. Other fishes that have also been mischaracterized as having barbels, include Acipenseriformes, artedidracoids, cyprinids, gadids, osteoglossids, and triportheids. These all have cirri rather than barbels.

S10-11 Gemmell, BJ*; Hawkins, O; Colin, S; Sutherland, K; Costello, J; University of South Florida, Roger Williams University , University of Oregon, Providence College; *bgemmell@usf.edu*

Propulsion and predation in a uniquely shaped oceanic ctenophore

Cestum veneris is a pelagic ctenophore found throughout temperate and tropical oceans. Despite their widespread distribution, we know little about their propulsive capabilities and prey capture mechanisms due to their fragile nature and inability to survive for even modest periods in the laboratory. *Cestum spp.* have a unique morphology among the Ctenophora, with an elongate, wing-like body shape. Using field-based methods for high speed, brightfield imaging and particle image velocimetry (PIV), we quantify details of the propulsive structures and interactions with prey. We find that these animals continuously cruise through the water at high relative speeds for gelatinous zooplankton (>10 cm s^{-1}). Unique among ctenophores is that all of the propulsive ctenes are located at the distal end of the animal and arranged in two bands that span the entire length. Kinematic details and fluid dynamic data are used to discuss the implications for this mode of propulsion and prey capture in this rarely studied species.

67-4 Genovese, CB*; Moran, AM; Jewell, M; Marko, P; University of Hawaii at Manoa; *cbgenovese@gmail.com*

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Plasticity in egg size of the tropical marine polychaete Hydroides elegans

Temperature is a key factor in determining the physiology and distribution of marine species and the projected rates of ocean warming are likely to outpace the ability of species to adapt. Phenotypic plasticity in traits correlated with fitness and survival offers an alternative, more rapid strategy for dealing with environmental changes. In this study we wanted to investigate phenotypic plasticity in two maternal traits, egg size and energy content, in relation to environmental temperature in the marine polychaete . Both these traits are important fitness components, but the relationship between the two is rarely explored empirically. collected from Pearl Harbor, HI were kept at 25° C in a common garden for a minimum of two generations and then newly settled juveniles were split into either 20 or 28° C until reproductive maturity. Gravid adults were then spawned and eggs from 20-25 females reared at each temperature treatment were collected to perform measurements of egg size and energy content, as well as fecundity. Females reared at 20° C produced eggs twice as large and had higher fecundity than females reared at 28° C, consistent with the temperature-size rule. To determine whether this difference in egg size reflected a difference in maternal investment strategies, we measured egg energy content using a dichromate oxidation technique. However, females reared at 28° C produced eggs with almost twice the energy content and energy density than females reared at 20° C. These results are counter-intuitive and suggest that temperature-driven changes in egg size do not reflect a decrease in per-offspring investment in this species. These results may be driven by either changes in egg composition or a selective strategy to avoid polyspermy while providing more energy in the egg to fuel the rapid metabolic rates of larvae.

71-4 George, AB*; Westneat, MW; Field Museum of Natural History, University of Chicago; *ageorge@fieldmuseum.org*

Three-dimensional kinematic analyses reveal asymmetries in Xanthichthys auromarginatus (Balistidae) median fin biomechanics during steady balistiform swimming

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Triggerfishes and filefishes in the superfamily Balistoidea rely on coordination of positionally and morphologically asymmetrical dorsal and anal fins to power steady balistiform swimming. The biomechanics of this asymmetrical paired-propulsor systems remain poorly understood, largely due to the difficulty of filming dorsal and anal fins simultaneously. In this study, we used a three-camera high-speed video system to analyze 3D dorsal and anal fin ray swimming kinematics of gilded triggerfish, *Xanthichthys auromarginatus*. We hypothesized that the morphological asymmetries observed between *X. auromarginatus* dorsal and anal fins would result in biomechanical asymmetries between these fins during steady swimming. Results revealed that dorsal and anal fin rays exhibit coordinated, yet significantly different kinematic properties both along and between the median fins, with leading edge fin rays providing nearly half of the total propulsive effort. All dorsal and anal fin rays oscillate from left to right with the same frequency, but nearly all other studied kinematic traits differ between rays. The larger dorsal fins exhibit higher amplitude fin ray undulations, lower wave speeds, lower wave lengths, and provide an overall greater percentage of total propulsive effort than the anal fins. Given that *X. auromarginatus* possess fairly morphologically symmetrical median fins among balistoid fishes, the biomechanical fin asymmetries observed in this study likely occur across a wide range of balistoid species, challenging the long-standing assumption of symmetrical median fin biomechanics in balistoid fishes. Funded by NSF GRFP 1144082 and 1746045, IOS 1425049 and DEB 1541547.

BSP-1-8 George, EM*; Rosvall, KA; Indiana University Bloomington; *georgee@indiana.edu*

Uncovering the bidirectional link between testosterone and aggression in a female songbird

Social competition is ubiquitous in nature, but social environments are seldom static. Instead, they can change as conspecific challengers come and go. Social environments also shift over weeks and months as animals move through different life history stages that shape the relative costs and benefits of competition. Animals should respond to social competition with phenotypes that enhance their success, such as aggression. There is strong evidence in male

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vertebrates that aggression is mediated by the steroid hormone testosterone (T) over multiple timescales, but whether and how this applies to females is unclear. We have been systematically testing these ideas in female tree swallows (*Tachycineta bicolor*), an obligate secondary cavity-nesting songbird species in which aggression a) is beneficial for obtaining and defending nest sites, b) can interfere with parental care, and c) is at least partially mediated by T. In a series of studies, we showed that females rapidly respond with intense aggression to both experimentally-enhanced competition and simulated territorial intrusions. Population-average aggression decreases with date, and individuals who more plastically adjust aggression across breeding stages have higher fitness. Females exhibit greater T production capabilities during breeding stages with more frequent social challenges (territory-establishment) and reduced T levels during breeding stages with greater parental care demands (incubation, chick rearing). However, even during earlier breeding stages, females do *not* increase T levels following real or simulated contests. Together, these results shed new light on the relationship between T and female aggression across contexts and over varying timescales.

61-8 Ghalambor, CK*; Shah, AA; Landeira-Dabarca, A; Rugenski, AT; Encalada, AC; Thomas, SA; Flecker, AS; Poff, NL; Norwegian University of Science and Technology and Colorado State University, University of Montana, Universidad San Francisco de Quito, University of Georgia, Universidad San Francisco de Quito, University of Nebraska, Cornell University, Colorado State University; *cameron.ghalambor@ntnu.no*

Comparing thermal performance curves for metabolic rate, growth, and locomotion: evidence for tropical specialists and temperate generalists?

A fundamental question at the interface of evolution and physiology is to understand how natural selection shapes the thermal sensitivity of traits. Gilchrist (1995) provided a model to explain how thermal performance curves should evolve under variable and constant environments. Here we compare thermal performance curves for metabolic rate, growth rate, and locomotor performance in temperate and tropical mayfly larvae from different elevations.

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Mayfly larvae from these sites differ in the amount of seasonal and daily temperature variation they experience. We found metabolic rate increased more quickly and growth rates to be lower in tropical compared to temperate species regardless of elevation. Locomotor performance did not show any clear differences except between low elevation species, where temperate species had broader thermal breadth compared to their tropical counterparts. We discuss these results in light of the assumptions and predictions put forward by Gilchrist (1995) and how they relate to the evolution of generalist-specialist continuum.

88-7 Ghione, CR*; Coradini, A; Ehrenreich, I; Dean, M; University of Southern California, University of Southern Caliornia; *ghione@usc.edu*
Molecular basis for copulatory plug in garter snakes
Copulatory plugs many organisms throughout the animal kingdom. While studies have discovered several proteins (SVS2, TGM4, PATE4) that are crucial to making copulatory plugs in rodents, the components that make the copulatory plug in other organisms, such as snakes, remain a mystery. My project aims to uncover the proteins that make up the copulatory plug in garter snakes.

S2-5 Ghiselli, F*; Milani, L; Iannello, M; Piccinini, G; University of Bologna, Italy; *fabrizio.ghiselli@unibo.it*
Bivalve molluscs as model systems for studying mitochondrial biology
The Class Bivalvia is a highly successful and ancient taxon (the second largest inside Mollusca) including ~25,000 living species. During their long evolutionary history (first appearance in the fossil record: 500+ Mya) bivalves adapted to a wide range of physical-chemical conditions (e.g.: salinity, temperature, pH, oxygen concentration, pressure), substrates (e.g.: buried into sediments, attached to hard surfaces), habitats (e.g.: rivers, lakes, estuaries, intertidal zones, coral reefs, ocean banks, continental shelves, deep waters), biological interactions (e.g.: free-living, simbionts, parasites), and feeding habits (e.g.: filtering, scraping, predation). Bivalves can have strikingly different dimensions (from less than 1 millimeter to 1+ meter), and

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despite their apparently simple body plan, they evolved very different shell shapes, and complex anatomic structures, such as eyes and mantle modifications for host-attraction. One of the most striking features of this class of animals is their peculiar mitochondrial biology: bivalves have facultatively anaerobic mitochondria that allow them to survive prolonged periods of anoxia/hypoxia; moreover they show the only known evolutionarily stable exception to the strictly maternal inheritance of mitochondria. Such phenomenon is called doubly uniparental inheritance, and has been reported, so far, in 100+ species. Mitochondrial activity is fundamental to eukaryotic life and bivalves, thanks to their diversity and uncommon features, represent a great opportunity to expand our knowledge about mitochondrial biology, which right now is limited to a few species. An integrated approach is the only possible way to be successful in such endeavour, so it will be necessary to build a strong collaborative relationship between genomics and physiology.

60-6 Giambrone, SA; Beveridge, J; Haynes, L; Fish, O; Lose, B; Reed, L; Scott Chialvo, C*; University of Alabama, Appalachian State University; *chialvoch@appstate.edu*

Contribution of the gut microbiome to toxin tolerance in mushroom feeding Drosophila

The evolutionary arms race between phytophagous insects and their hosts has long fascinated biologists. Plants and fungi evolved a wide variety of secondary chemicals that are hypothesized to provide defense. While these compounds render them distasteful or toxic to many herbivores, some insects retain the ability to use them as hosts. Understanding the mechanisms that allow phytophagous insects to consume chemically defended hosts remains an active area of research, and recent studies have begun to highlight the role of the gut microbiome in assisting with toxin metabolism. In this study, we examine the potential contribution of the gut microbiome to toxin tolerance in mushroom-feeding *Drosophila* in the *immigrans-tripunctata* radiation. These flies and their larvae are broadly polyphagous on a wide range of fleshy mushrooms including toxic *Amanita* species that produce cyclopeptide toxins. Very little is known about the mechanism(s) of toxin tolerance in the *immigrans-tripunctata* radiation beyond the fact that its

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species do not have mutations that would inhibit the toxins' mode of action. To assess the role of the microbiome in detoxification, we reared larvae of six tolerant species on diets with and without the toxin α-amanitin after significantly altering their microbiome. To quantify the contribution of the microbiome, we measured several performance phenotypes, including survival to adulthood and thorax length. Our results demonstrated that the gut microbiome does not play a critical role in cyclopeptide tolerance within the *immigrans-tripunctata* radiation.

7-6 Giammona, FF*; Minicozzi, M; Ashley-Ross, MA; Wake Forest University, Minnesota State University; *giamff17@wfu.edu*

Caudal and column changes: tail and vertebral spine adaptations in amphibious cyprinodontiformes

Amphibious fishes, which spend any natural part of their life history out of water, are a subject of interest due to the adaptations which allow them to survive both on land and in water. In particular, the order Cyprinodontiformes contains many amphibious species. These species are closely studied because while they have many adaptations for living on land, their body plans are similar to that of a solely aquatic bony fish. This begs the question: do amphibious Cyprinodontiformes have subtle anatomical adaptations which allow them to better locomote and survive on land? Amphibious Cyprinodontiformes move on land primarily by performing a "tail-flip", in which the anterior of the body curves up and over the posterior, and then the tail pushes off the ground to launch the fish into the air. Given this reliance on the spine and tail, the vertebral column and caudal region of amphibious and non-amphibious Cyprinodontiformes fishes were examined. In particular, the hypural plate, epurals, and parahypurals of the tail, and the neural and hemal spines throughout the vertebral column were compared. Previous studies have shown variation in jumping performance within an amphibious species that correlated with hypural and epural differences, and those patterns are expected to be upheld in this dataset. Geometric morphometrics was also employed to quantify body shape differences between species. By determining which anatomical changes allow for amphibious behavior, we will better be able to predict the present behavior of

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potentially amphibious fishes, and speculate at the behavior of extinct fish species.

86-4 Giancarli, SM*; Dunham, AE; O'Connor, MP; Drexel University, Philadelphia, PA, University of Pennsylvania, Philadelphia, PA; *smg432@drexel.edu*

Clade-specific metabolic allometries in the non-avian reptiles

For the past two decades the foremost hypothesis for the driver of metabolic allometries has been the Metabolic Theory of Ecology (MTE) despite considerable dispute since its conception. MTE posits that all metabolic allometries are a result of the optimization of the circulation of blood and resources throughout an organism's body, and that these relationships have a universal allometric scale power of 0.75 with no variation between or among groups of organisms. Previously, we have found that the allometric slope of resting metabolism varied among clades in mammals and birds, along with inconsistencies in many of these clade-specific allometries with MTE's proposed value. To investigate these relationships in ectotherms, we are now investigating whether or not this same clade specificity exists in the non-avian reptiles. Testing this hypothesis in the non-avian reptiles is of significance to us because, while a paraphyletic group, they are not endotherms and have metabolisms dependent on ambient temperature. The diversity of the non-avian reptiles also brings a variety of physiologies to consider in both our analyses and the interpretation of our data. We have compiled over 1000 resting metabolic measurements of over 200 non-avian reptile species, including body mass and temperature. A preliminary linear model (not phylogenetically corrected) shows an overall slope of around 0.77 and suggests significant influence of taxonomy at the ordinal level on both the slope and intercept. We impose a hypothesized allometric tree on the data to investigate taxonomic variation in metabolism and thermal effects at the sub-ordinal level.

105-3 Gibbs, BJ*; Akanyeti, O; Liao, JC; University of Florida, Gainesville and Whitney Lab for Marine Bioscience, St. Augustine, Aberystwyth University, UK; *brendan.gibbs@ufl.edu*

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Pectoral fin kinematics and electromyography in Karman gaiting trout

Pectoral fin activity is important for a range of behaviors in fishes, including propulsion and maneuvering. How these paired fins are used to navigate unsteady flows is less understood, despite their prominent use in stream-dwelling fishes such as rainbow trout (*Oncorhynchus mykiss*). We investigated the muscle activity of pectoral fins in four trout (L= 21.7 ±0.837 cm) Karman Gaiting behind a 5 cm D-cylinder across a range of five flow speeds (2 L s_{-1} – 3.75 L s_{-1}). Electromyography recordings for both the superficial and deep layers of the pectoral fin abductor and adductor muscles were collected with simultaneous high-speed video to reconstruct pectoral fin motion and muscle activity. Pectoral fin motions were observed during Karman Gaiting which co-occurred with activity from the abductor muscles. Our data suggest that Karman Gaiting fish use their pectoral fins to interact with vortical flows in a manner that allows them to employ passive or trimming forces to adjust their position. When a major body correction is needed, especially when fish were re-positioning themselves or re-entering the vortex street at high speeds, both the abductor and adductor muscles are highly active. At high flows, adductors and abductors showed the highest activity when coinciding with the initiation of braking motions, which occurred when trout approached the cylinder suction zone.

80-10 Gibson, JC*; Suarez, AV; University of Illinois at Urbana-Champaign; *jcgibso2@illinois.edu*

Functional morphology and biomechanics of trap-jaw ants in the Daceton genus group

Latch-mediated spring actuated (LaMSA) mechanisms have evolved independently in many groups of organisms across the tree of life, including multiple times in ants (Hymenoptera: Formicidae). "Trap-jaw" ants possess spring loaded mandibles that allow them to swiftly incapacitate or kill elusive prey. Trap-jaw ants have the potential to serve as model organisms for studies on the relationship between morphological and functional diversity and the evolution of LaMSA mechanisms, but to date the feasibility of these studies is limited by a lack of performance data for many groups of trap-jaw ants. Here we use high speed videography and micro-CT to

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describe the functional morphology, strike kinematics, and latch performance of representative species from the *Daceton* genus group, which consists of the genera *Acanthognathus*, *Colobostruma*, *Daceton*, *Epopostruma*, *Lenomyrmex*, *Mesostruma*, *Microdaceton*, and *Orectognathus*. We found that *Epopostruma* and *Orectognathus* close their mandibles asynchronously, presumably by unilaterally contracting their labral adductor muscles, despite possessing a latching mechanism that is morphologically analogous to a separate trap-jaw ant group (*Strumigenys*) known to produce synchronous mandible closure. An exception is the soldier caste of the polymorphic species *Orectognathus versicolor*, which close their mandibles synchronously. We also show that, surprisingly, species in the genera *Colobostruma* and *Mesostruma* possess a mandible latching mechanism, suggesting that they are using a LaMSA mechanism despite lacking the mandible modifications present in other genera in this group. This study is part of a larger project examining the biomechanics and evolution of LaMSA mandibles in ants.

48-6 Gibson, MJS*; Torres, ML; Brandvain, Y; Moyle, LC; Indiana University, Bloomington, Indiana, Universidad San Francisco de Quito, Quito, Ecuador; Galapagos Science Center, San Cristobal, Galapagos, Ecuador , University of Minnesota-Twin Cities, St. Paul, Minnesota; *gibsomat@indiana.edu*

Reconstructing the history and biological consequences of a plant invasion on the Galapagos Islands

The introduction of non-native species into new habitats is one of the foremost risks to global biodiversity. Here, we evaluate a recent invasion of wild tomato (*Solanum pimpinellifolium*) onto the Galapagos islands from a population genomic perspective, using a large panel of novel collections from the archipelago as well as historical accessions from mainland Ecuador and Peru. We infer a recent invasion of *S. pimpinellifolium* on the islands, largely the result of a single event from central Ecuador which, despite its recency, has rapidly spread onto several islands in the Galapagos. By reconstructing patterns of local ancestry throughout the genomes of invasive plants, we uncover evidence for recent hybridization and introgression between *S. pimpinellifolium* and the closely related endemic species *Solanum cheesmaniae*. Two large introgressed

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regions overlap with known fruit color loci involved in carotenoid biosynthesis. Instead of red fruits, admixed individuals with endemic haplotypes at these loci have orange fruit colors that are typically characteristic of the endemic species. We therefore infer that introgression explains the observed trait convergence. Moreover, we infer roles for two independent loci in driving this pattern, and a likely history of selection favoring the repeated phenotypic transition fro m red to orange fruits. Together, our data reconstruct a complex history of invasion, expansion, and gene flow among wild tomatoes on the Galapagos islands. These findings provide critical data on the evolutionary importance of hybridization during colonization and its role in influencing conservation outcomes.

111-2 Giffin, JL*; Franz-Odendaal, TA; Mount Saint Vincent University, Halifax, Nova Scotia, Canada; *Jennifer.Giffin@msvu.ca*
Placode induction and patterning cues in the embryonic chicken scleral ossicle system
The avian eye is supported by a ring of evenly-spaced bony elements known as the scleral ossicles. The formation of these bones is directed by a series of conjunctival papillae, elongated epithelial structures that arise from placodes. Expression of some genes, such as β-catenin and the receptors for fibroblast growth factor (FGF), is known to occur in the developing conjunctival placodes and papillae (CPP). However, expression of genes from three other families important in epithelial placode systems, namely bone morphogenetic protein (BMP), ectodysplasin (EDA) and hedgehog (HH), was expected, although it had not been definitively shown. Therefore, the objective of this study was to analyze gene expression of the β-catenin, FGF, BMP, EDA and HH signalling pathways throughout CPP induction using a qPCR approach. The results indicate that at least two members of each of the five signalling pathways were expressed throughout CPP induction, with most genes exhibiting an initial increase in expression, followed by a decrease or a sustained expression level. Correlation analyses reveal the existence of two distinct gene interaction modules. Additionally, differences in gene expression among the temporal, nasal and dorsal regions were present for some genes. Therefore, a conserved signalling network is present in CPPs and other

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epithelial appendages and these signalling molecules have two patterns of expression, which may differ according to the specific eye region. The detailed spatiotemporal gene expression dynamics occurring throughout CPP induction are consistent with the presence of a molecular and potentially a mechanical patterning mechanism, as found in other placode systems.

19-13 Giglio, EM*; Campbell, P; Phelps, SM; University of Texas at Austin, University of California at Riverside; *eringiglio@gmail.com*
Acoustic variation across social contexts in neotropical singing mice (S. teguina)
Animal communication is by nature a dynamic interaction between signaler and audience. The same signal may serve many different functions among different audiences and individuals might tailor signals in different ways depending audience. Singing mice (Scotinomys teguina) are small rodents which have recently captured attention for their loud, long, elaborated song. However, the vocalizations of S. teguina have rarely been studied across social contexts. Here we examine vocalizations of focal S. teguina males produced both alone, in the presence of unfamiliar males, and in the presence of both familiar and unfamiliar females. We find that singing mice produce not one but two distinct types of songs, the well-studied long advertisement song and a shorter, quieter "strophe" song. The songs are produced in different contexts, with strophe songs in particular produced almost entirely in the context of female audiences. Additionally, we find that both advertisement songs and strophe songs change in structure when produced in different circumstances. Finally, we note that both advertisement songs and strophe songs contain considerable information about individual identity, raising the possibility that mice may be able to identify familiar individuals from songs alone.

49-2 Gladstone, NS*; Johnson, PD; Whelan, NV; School of Fisheries, Aquaculture and Aquatic Sciences, Auburn University, Auburn, AL, Alabama Aquatic Biodiversity Center, Alabama Department of Conservation and Natural Resources, Marion, AL , School of Fisheries, Aquaculture and Aquatic Sciences, Auburn University, Auburn, AL; Southeast Conservation Genetics Lab, Warm Springs Fish

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Technology Center, United States Fish and Wildlife Service, Auburn, AL ; *nsg0012@auburn.edu*

Evolution of egg laying behavior in a critically imperiled freshwater gastropod family (Cerithioidea: Pleuroceridae)

The evolution of divergent life history strategies can be implicated in the promotion of ecological opportunity and species diversification. The Pleuroceridae (Cerithioidea) is a biodiverse and geographically widespread family of freshwater gastropods that occupy numerous freshwater ecosystems in North America east of the Rocky Mountains. Previous studies have shown substantial variability of life history traits between species. This variation is relatively unique as most freshwater gastropod families display similar life histories. In particular, egg-laying behaviors among pleurocerid species can be sorted into several unique modalities: singly-laid eggs, multiple singly-laid eggs, small individual lines of eggs, circular egg clutches, and eggs laid together in large strip-clutch formations. Here, we examine these behaviors in a robust phylogenetic context using ancestral character reconstruction to understand the evolution of these egg-laying behaviors and whether convergence shapes contemporary patterns. Our results indicate that a discrete clutch egg-laying behavior has evolved convergently at least three times with no reversals, possibly suggesting repeated evolution of increased parental investment when laying eggs. The strip clutch behavior has evolved a single time, also with no reversal. In contrast, although there are several instances of independent evolution of laying eggs singly or in single lines, these behaviors appear to be more vagile.

107-8 Glass, JR*; Harrison, JF; Arizona State University, Tempe, AZ, USA; *jrglass@asu.edu*

Interactive effects of air temperature and density on flight physiology of honey bees

Though it is well-known that honey bees thermoregulate during flight, the mechanisms remain controversial. Studies have reported constant metabolic rate and wing beat frequency across different air temperatures, while others found declining metabolism and wing beat frequency as air temperature rises. One confounding factor may be work-load during flight, which is challenging to control and

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manipulate in honey bees. To investigate how air temperature and increased power requirements affect flight metabolism, we flew foragers at 23° C and 35° C air temperatures and at air densities ranging from 21% O_2/79% N_2 to 21% O_2/79% He (1.288–0.441 kg·m^{-3}, normodense to heliox). Decreasing air density increases lift requirements, providing a way to test maximal aerobic performance during hovering flight. Flight metabolic rates of honey bees flown at 23° C air temperature were significantly higher than those flown at 35° C in normodense air. At 35° C air temperature, flight metabolic rate increased linearly by 1.4x as gas density decreased, and failure occurred in heliox, indicating a performance limit. In contrast, at 23° C air temperature, there was no increase in flight metabolic rate as air density decreased, and failure occurred sooner (at 0.779 kg·m^{-3}). At 23° C, thorax temperatures decreased linearly as air density fell, likely because helium increases convective and evaporative heat loss. Thermal performance curves for flight muscle predict these patterns, suggesting that flight muscle temperature plays a key role in determining the pattern of flight metabolic rate with changing air temperature and flight power requirements. Supported by USDA 2017-68004-26322.

27-2 Goerge, TM*; Miles, DB; Ohio University; *tg928517@ohio.edu*
The influence of conspecifics in thermal preference in tree lizards (Urosaurus ornatus)
Thermal preference is a laboratory-based measurement that is assumed to represent the body temperature an ectotherm would select in the wild. A proliferation of data on thermal preference has occurred recently because many studies use the metric for predicting the potential for species to cope with rapid changes in climate. However, the ability of an individual to attain physiological optimal body temperatures may be constrained by intra-specific competition for basking sites. To introduce a realistic constraint in thermal preference measurements, we measured preferred body temperature (T_{pref}) in tree lizards (*Urosaurus ornatus*) in (i) solo thermal gradient trials and in paired trials with (ii) individuals of the opposite sex, (iii) individuals of the same sex and same throat color morph, and (iv) individuals of the same sex and different throat color morph. We found clear evidence that conspecifics influenced T_{pref} in *U.*

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ornatus. When two males shared a gradient, T_{pref} values decreased significantly compared to solo values, regardless of if the competing males were of the same or different color morph. Males with partially blue throats were displaced the least, indicating dominance in thermoregulatory interactions, and males with non-blue throats (yellow or orange morphs) were displaced the most. Females were significantly displaced from their solo T_{pref} values when sharing a gradient with females of the same color morph and with males, while males were not displaced by females. Including realistic constraints in T_{pref} measurements likely provides a more accurate depiction of thermoregulation in tree lizards, and similar measurements with realistic constraints introduced could be used to inform more accurate models predicting species responses to climate change.

19-10 Goldberg, DL*; Sadd, BM; Capparella, AP; Illinois State University; *dlgoldb@ilstu.edu*

A rallid ballad: Correlates of communal signaling in the rails (Rallidae), a model system for studies of avian duets

Most studies of avian communal signaling - individuals calling in coordinated unison - have focused on songbirds. Yet duets occur in 40% of species in the family Rallidae (rails and allies), one of the highest known rates of any bird family. We used a comparative approach to study links between duetting and life history traits, mass, habitat type, and call measurements across 90 rallid species. We predicted that duetters show long-term pair bonds and year-round territoriality, inhabit dense vegetation and produce low-frequency calls that spread well over short distances, and have similarly sized males and females; unlike non-duetters, in which the calling sex (males) should be larger. Phylogenetic generalized linear mixed-effect models found that duetting is significantly associated with year-round territoriality and lack of migration, and forest-dwellers are more likely to duet than species in open or heterogeneous habitats. Contrary to predictions, phylogenetic MANOVAs found that duetters call at higher frequencies, and no significant correlation exists between duets and pair bond length or size dimorphism. Our results indicate that rallids fit some, but not all, expected patterns seen in duetting birds generally. Despite the prevalence of duets in rallids, no experiments have

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tested duet functions such as resource defense in these understudied birds, and our evolutionary study lays the groundwork for future research. The innateness of rallid calls, in contrast to the learned calls of most songbirds, suggests that the causation and survival value of duetting, and possibly its behavioral purposes, differ in rails from the traditional avian study system.

33-2 Gómez-Corrales, M*; Prada, C; University of Rhode Island; *matias_gomez@uri.edu*

Cryptic lineages matter for coral conservation under climate change

Coral cover is decreasing worldwide largely as a result of a rise in seawater temperatures that triggers coral bleaching and induces coral mortality. Therefore, understanding coral physiological response to rising ocean temperatures poses a challenge for reef conservation. A central aspect of managing coral reefs under global warming lies in accurate species identification and their potential to withstand thermal stress. Cryptic species, morphologically similar but genetically different, typically harbor distinct physiological variation and will respond differently to climate change. A dominant Caribbean reef builder severely affected by climate change is the Mountainous Star Coral, *Orbicella faveolata*. A recent study reported quantitative genetic variation in the physiological response to thermal stress in a single population of this species, suggesting that variation within populations will allow these corals to adapt to rising ocean temperatures. However, we reanalyzed the data and found multiple cryptic lineages rather than a single panmictic population, with one of the lineages being not heat-tolerant. Our finding of hidden lineages within a threatened species highlights the varying extinction risks faced by these independently evolving groups.

BSP-4-2 Gomez-Picos, P*; Ovens, K; Eames, BF; University of Saskatchewan; *pag410@mail.usask.ca*

A conserved transcriptional program underlies mesoderm- and neural crest-derived chondrocytes

Cartilage is composed of chondrocytes of distinct embryonic origins, mesoderm and neural crest (NC), but the degree of

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similarity between chondrocytes derived from the distinct embryonic lineages is still debatable. During endochondral ossification, two types of chondrocytes differentiate in the head and limb skeletons, immature chondrocytes (IMM) and mature chondrocytes (MAT), so both cell types can derive from the mesoderm or the neural crest. To test the hypothesis that the transcriptomes of mesoderm- and NC-derived chondrocytes are conserved, LCM was used to isolate IMM and MAT from two endochondral bones in the chick limb and head, the humerus and the ceratobranchial, which are mesoderm- and NC-derived, respectively. Venn diagram analyses revealed that the humerus and ceratobranchial transcriptomes show a high degree of conservation. Although they exhibit some differences in gene expression, the fundamental set of genes driving cartilage differentiation including *SOX9*, *COL2A1*, and *COL10A1* was generally conserved. Indeed, some enriched biological processes in genes shared between the humerus and the ceratobranchial are related to skeletal cell differentiation. In contrast, GO analyses revealed that enriched biological processes in the humerus are related to limb/forelimb morphogenesis whereas enriched terms in the ceratobranchial are related to neural crest-dependent processes. Together these results suggest that the molecular program driving cartilage differentiation is conserved regardless of embryonic origin or location in the body. Adding more clades into these transcriptomic comparisons can make this conclusion more robust and might provide novel insights into mechanisms of differentiation and evolutionary origins of cartilage.

S11-9 Gompper, ME; New Mexico State University; *gompperm@nmsu.edu*
Thinking globally about dog populations and their wildlife conservation relevance
Course estimates suggest that the global domestic dog population comprises nearly 1 billion animals. While the potential for these animals to have an impact on global wildlife conservation efforts are increasingly recognized, often this recognition lack nuance. As such, there is the potential for generalizations about dogs that are, at best, unfounded, and at worst, lead to harmful policy and welfare (for wildlife and for dogs) decisions. Here I examine patterns of variance in dog population sizes and in how humans interact with dogs. I then briefly review four ways in which dogs

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are believed to influence wildlife: as predators, as prey, as competitors for resources (including mates), and as potential reservoirs for pathogens. I then identify common generalizations about the need for dog management: the need to increase veterinary care, the need for enhanced nutritional husbandry, the need to limit free-ranging behaviors, and the need for population reductions. Each of these management approaches involve potentially significant fiscal and non-fiscal costs, some of which may also negatively affect wildlife.

29-3 Gonzalez, P*; Baxevanis, AD; National Human Genome Research institute, National Institutes of Health; *paul.gonzalez@nih.gov*

Large-scale characterization of non-coding conserved elements across the Metazoa

Some of the most important innovations in animal evolution were not driven by the evolution of new genes but instead resulted from changes in the regulation of conserved genes. These changes involve non-coding regulatory elements that are difficult to identify based on DNA sequence alone. However, potential regulatory sequences can be identified using a comparative evolutionary approach, searching for conserved non-coding elements (CNEs) that have been under purifying selection over large evolutionary time scales. Here, we conduct a large-scale characterization of CNEs across animal genomes. Using the k-mer based tool CNEfinder and a Python-based custom pipeline, we compared more than 50 metazoan genomes distributed among 16 animal phyla, resulting in more than 800 pairwise comparisons. For each comparison, we identify all sequences between 150 bp and 2 kb showing more than 90% sequence similarity. We have characterized the distribution of CNEs along chromosomes, annotated CNEs with their nearby genes, and scanned every CNE for known transcription factor binding sites. For each genomic dataset, we identified CNEs that remain in proximity with homologous genes across multiple species. We hypothesize that genes that 'travel' in close proximity to the same CNEs over large evolutionary time may be the transcriptional targets of these CNEs. Finally, we assess the distribution of each CNE on the animal tree to determine at which node they likely arose. We are currently using these data to identify candidate CNEs that may be involved in the evolution of taxon-specific traits.

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37-8 Goodheart, JA*; Bigasin, A; Lyons, DC; UC San Diego; *jgoodheart@ucsd.edu*

Investigating the molecular mechanisms of nematocyst sequestration in the emerging nudibranch model Berghia stephanieae

Phagocytosis and storage of structures or cells from one organism inside the cells of another is fundamental to early eukaryote evolution. However, multiple metazoan lineages have secondarily evolved the ability to sequester structures from their diet. Many groups have evolved such interactions for metabolism (i.e., dinoflagellate symbiosis in corals), but few have done so to boost defensive capabilities. The processes of recognition, phagocytosis, and long-term stability of sequestered cells has been relatively well-studied in cnidarian-dinoflagellate symbiosis. By comparison, little is known about these processes in organisms that sequester putatively defensive structures, such as nematocysts, or how those processes compare with symbiotic interactions. Here, we investigate the underlying mechanism of nematocyst sequestration in an emerging gastropod model, *Berghia stephanieae*, an aeolid nudibranch well known for its voracious predation on the anemone *Exaiptasia*. During the digestive process, putatively immature *Exiptasia* nematocysts move through the digestive tract to a structure called the cnidosac, where they are phagocytosed by cells called cnidophages. We studied features of the cnidophage cell type using traditional histological methods, antibody staining, and differential expression analysis. We identified key morphological differences within the cnidophage cell type, along with 65 upregulated transcripts, including those that may be associated with cnidophage development or with the instigation of phagocytosis. We are also developing methods, such as in situ hybridization, to validate the functional significance of these candidate genes.
Since *Exaiptasia* is already well-studied, the development of such tools in *Berghia* will provide a unique system in which both sides of the sequestration process can be studied in detail.

82-6 Gordus, A*; Corver, A; Wilkerson, N; Miller, J; Johns Hopkins University; *AGORDUS@JHU.EDU*

Untangling the web of behaviors used in spider orb weaving

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Many innate behaviors are the result of multiple sensorimotor programs that are dynamically coordinated to produce higher-order behaviors such as courtship or architecture construction. Extended phenotypes such as architecture are especially useful for ethological study because the structure itself is a physical record of behavioral intent. A particularly elegant and easily quantifiable structure is the spider orb-web. The geometric symmetry and regularity of these webs have long generated interest in their behavioral origin. However, quantitative analyses of this behavior have been sparse due to the difficulty of recording web-making in real-time. To address this, we have developed a novel assay enabling real-time, high-resolution tracking of limb movements and web structure produced by the hackled orb-weaver *Uloborus diversus*. With its small brain size of approximately 100,000 neurons, the spider *U. diversus* offers a tractable model organism for the study of complex behaviors. Using deep learning frameworks for limb tracking, and unsupervised behavioral clustering methods, we have developed an atlas of stereotyped movement motifs and are investigating the behavioral state transitions of which the geometry of the web is an emergent property. In addition to tracking limb movements, we have developed algorithms to track the web's dynamic graph structure. We aim to model the relationship between the spider's sensory experience on the web and its motor decisions, thereby identifying the sensory and internal states contributing to this sensorimotor transformation.

104-2 Gould, FDH*; Lammers, AR; Mayerl, CM; German, RZ; Rowan School of Osteopathic Medicine, Cleveland State University, NEOMED, NEOMED; *gouldf@rowan.edu*

Heterogeneity of variance partitioning between kinematics and electromyography (EMG) of swallowing following nerve lesion in pigs

Variation in cyclical behaviors can be partitioned among hierarchical levels. Understanding how variation is partitioned is important for identifying what level is most likely associated with differences in performance. The effect of recurrent laryngeal nerve lesion on swallowing kinematics and muscle function is highly variable among individuals. However whether variation is

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partitioned similarly among individuals, lesion status, and swallow cycle in kinematics and EMG variables is unknown. We hypothesize that because muscle activation patterns produce kinematics, we will see similar patterns of hierarchical variation in kinematics and EMG. We recorded high speed videofluoroscopy and EMG of six infant pigs drinking milk mixed with barium. We digitized radiopaque markers to calculate three kinematic variables for every swallow. We calculated duration and timing of onset of muscle activity during swallows for seven oropharyngeal muscles before and after recurrent laryngeal nerve lesion. We scored swallows for successful airway protection using an ordinal scale. We used a hierarchical nested model to partition variance among airway protection, cycle, lesion status, and individual. Variance partitioning did not follow similar patterns in EMG and kinematic data. Between cycle variation was greatest in kinematics, while between individual variation was greatest in timing and duration of EMGs. The amount of variation attributed to experimental factors is highly variable though consistently less than non-experimental factors. The different patterns of hierarchical variation in muscle activation and kinematics suggest potentially different responses to functional challenges.

94-12 Goyal, P*; Cribellier, A; Croon, G; Lankheet, M; Leeuwen, J; Pieters, R; Muijres, F; Wageningen University and Research, Netherlands, Delft University of Technology, Netherlands; *pulkit.goyal@wur.nl*

Bumblebees land by adjusting the set-point of optical expansion rate in a stepwise manner

As flying animals approach a surface for landing, they decelerate to reduce their momentum at impact. This deceleration is based on the radial optic flow that animals can use to compute relative-rate-of-expansion. Our knowledge of how they use these expansion cues to decelerate remains limited. Here, we studied how bumblebees (*Bombus terrestris*), which are important pollinators in nature and horticulture, use these expansion cues to decelerate during landings over short distances. We used machine-vision techniques to analyse the flight dynamics of 4,672 landing manoeuvres as bumblebees approached vertical platforms with two different visual expansion cues, and in luminance ranging from twilight to sunrise.

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By using a novel analysis approach focussed on individual landing manoeuvres, we show that bumblebees exhibit a series of deceleration bouts, unlike honeybees that exhibit one deceleration phase in long-distance landings. During each bout, bumblebees keep their relative-rate-of-expansion constant at a particular set-point, and from one bout to the next, they shift to a higher set-point as their distance from the platform reduces. As a result, the average change of set-points with distance occurs at a value strikingly similar to pigeons and hummingbirds. This newly-described landing strategy resulted in relatively quick landings, also in dim light condition and with limited visual expansion cues, and has potential use in autopilots governing landings in flying robots.

19-2 Graham, ZA*; Angilletta, M; Arizona State University, School of Life Sciences, Tempe, AZ; *zgraham1@asu.edu*

Separating noise and function in systems of animal communication: a comparative study of aggressive signaling in crayfish

A primary issue in the study of dishonest signaling is the researcher's ability to detect and describe a signal as being dishonest. However, by understanding the relative honesty of a signal as a statistical property of an individual or population, researchers have recently quantitatively described dishonest communication. Thus, dishonest signals can be understood as when there is a breakdown in the correlation between a signal and its underlying meaning; creating variation within a signaling system. However, such variation in signaling systems may not be attributed to dishonesty, because of inherent noise within biological systems driven by evolutionary or physiological noise. Here, we try to separate out functional variation within honest or dishonesty signaling systems from inherent biological noise by leveraging homologous structures that have evolved for separate functions - the enlarged claws of freshwater crayfish. Because burrowing species of freshwater crayfish claws have not evolved as signals, the variability in the size and strength of their claws should be minimal when compared to claws of non-burrowing species that evolved as signals during aggression. We found that despite the claws of burrowing and non-burrowing crayfish claws having evolved to serve difference functions, the claws of all species in our

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study were inherently noisy. Furthermore, although claws that unreliably correlate predict the strength of wielder may function as dishonest signals in other crustaceans, we did not find support for this hypothesis; because crayfish escalated aggression based on relative body size.

74-5 Graham, M*; Clemente, CJ; Socha, JJ; Virginia Tech, Blacksburg, Virginia, USA, University of the Sunshine Coast, Sippy Downs, Australia; *grahmich@vt.edu*

Body size influences transition to dynamic gap crossing movements in australian tree snakes

Many animals use dynamic behaviors to cross gaps larger than those they can reach across. Despite the generality of this pattern, the factors that influence the selection of gap-crossing behaviors are not fully understood. In snakes, the relationship between gap distance and behavior has rarely been studied, in part because most species exhibit only one crossing behavior, the cantilever. Here, we examined gap crossing in wild-caught Australian tree snakes (genus: *Dendrelaphis*). It is possible that these arboreal snakes employ dynamic behaviors to extend their reach, similarly to their sister taxon to the flying snakes (*Chrysopelea*), who employ jumping to cross large gaps. We hypothesized that tree snakes would transition to a dynamic behavior prior to reaching their maximum cantilever distance (~50% snout-vent length (SVL)), but that larger snakes would transition relatively earlier because of disproportionate mass-related torques. To address this hypothesis, we recorded horizontal gap crossing in 19 specimens from two species (*D. punctulatus* and *D. calligastra*), and also collected morphometric data. Video recordings of trials revealed that the largest gap size at which a cantilever was used ranged from 38 to 56% SVL. In absolute terms, this distance scaled approximately 1:1 with snout-vent length. Beyond this distance, both species of *Dendrelaphis* used dynamic forms of crossing. Because growth is indeterminate in snakes, it is unclear whether this scaling pattern is due to body size or ontogeny, particularly as other behaviors varied between large and small snakes. These data support the general pattern of animals using dynamic behaviors to cross larger gaps, and suggest future directions for identifying factors that play a role in governing gap-crossing behavior selection.

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96-6 Granger, J*; Johnsen, S; Duke University; *jngranger@email.wm.edu*

Magnetoreception and the radio sun

Many animals can sense the earth's magnetic field and use it to perform incredible feats of navigation; however, the sense itself remains relatively enigmatic. Over the past 16 years, studies have repeatedly demonstrated that magnetic orientation can be disrupted by an oscillating magnetic field in the Radio Frequency (RF) range of 1-10MHz. While the physical pathway behind this disturbance is still being studied, little attention has been paid to the natural "RF-ecology" of a migratory animal. In this talk we aim to briefly summarize the behavioral evidence for RF-disruption and compare the thresholds seen in these experimental studies to the natural "RF-landscape" seen by magnetic migrators. The RF-ecology of an animal is characterized here by examining the most dynamic, natural source of 1-10MHz RF noise: the sun. While the atmosphere generally becomes opaque at frequencies lower than 10MHz, many natural phenomena can alter the transparency range of the atmosphere, allowing frequencies as low as 1MHz to reach the surface. In addition, the emission spectra of the sun in the RF-range varies greatly over time, occasionally even over-powering man-made sources of RF-noise. We aim to provide a quantitative summary of the natural "RF-environment" migratory animals are likely to encounter and provide context for how these phenomena can affect magnetoreception research.

S3-1 Green, PA*; Rico-Guevara, A; Centre for Ecology and Conservation, College of Life and Environmental Sciences, University of Exeter, Penryn, Cornwall, UK, Department of Biology and Burke Museum, University of Washington, Seattle, Washington, USA; *p.a.green@exeter.ac.uk*

Introduction to the symposium: Physical mechanisms of behavior

A central concept in organismal biology is understanding how organisms accomplish the tasks they face; that is, linking behavior with its underlying physical mechanisms including biomechanics, functional morphology, and physiology. Despite the utility of this approach and repeated calls for its broader use, studies of the

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physical mechanisms of behavior are rare. This may be because, for example, behaviorists have little background with the tools used in physical mechanisms research, while those studying physical mechanisms are inexperienced in linking their mechanistic understanding with broader behavioral principles. This symposium will reveal connections between behavior and physical mechanism on a diverse array of systems, helping other integrative biologists explore these links in their own research. The symposium is organized through a paired speaker structure: an expert on a given behavior will speak directly before or after an expert on the physical mechanism(s) underlying that, or a similar, behavior. Topics span a variety of essential tasks and their mechanisms, from how defensive structures function in predation avoidance, to the behavior and functional morphology of reproduction. Speakers will conduct shared question and answer sessions to help the audience better learn from and contribute to these collaborative conversations. The goal of this symposium is to leave attendees with inspiration and a toolkit for future work connecting behavior with its physical mechanisms.

S3-10 Green, PA*; Rico-Guevara, A; University of Exeter, University of Washington; *jjsocha@vt.edu*

Q&A on foraging and avoidance: Russell, Rico-Guevara, McHenry, Crofts, and Stankowich

This event is a question-and-answer session that focuses on foraging and avoidance, involving symposium speakers Russell, Rico-Guevara, McHenry, Crofts, and Stankowich.

74-2 Greenslit, NW; Erskine, OM*; Iijima, M; Blob, RW; Palecek, AM; Clemson University; *nwgreen@g.clemson.edu*

Acrobatic archosaurs: kinematic comparisons of climbing behaviors in turtles and alligators

The use of specialized habitats in animals is often correlated with specialized morphologies. However, some species make use of such habitats despite lacking these morphological specializations. What kinematic strategies might such species use to move through habitats for which their body plans are not advantageous? We examined this question by using high-speed video to film the

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climbing performance of stinkpot turtles (*Sternotherus odoratus*) and juvenile American alligators (*Alligator mississippiensis*) climbing up steep inclines (70°). Climbing is not regarded as a standard behavior of either species, but multiple videos have been filmed of alligators climbing fences, and stinkpots have been reported basking in treetops above water bodies. Though both species have short limbs relative to their body size, they show functional plasticity that enables them to meet the demands posed by such substrates. As a substrate becomes more inclined, the forelimbs and hindlimbs might be expected to use greater excursions, but with more crouched postures. We found differences in climbing footfall patterns compared to walking, and reduced velocity while climbing. Between species, both forelimb and hindlimb elevation was higher in alligators than in turtles while climbing. As an exaptation, alligators may also use the tail as a counterbalance contacting the surface while climbing, though stinkpots (with short tails) are unable to do so. The reduced plastron in stinkpots may allow for increased limb mobility conducive to climbing whereas other turtle species limbs would be restricted by the shell. These data have broad implications for better understanding the biomechanical and morphological traits necessary for new habitat invasions, improved biomimetic robot design, evolutionary function.

92-9 Greenway, EV*; Miller, CW; University of Florida; *egreenway@ufl.edu*

How does variation in the resource landscape influence mating dynamics in the insect Narnia femorata?

Sexual selection has historically been assumed to be a constant and consistent force, driving the evolution of elaborate traits such as animal weapons. However, organisms in the wild exist in heterogeneous and fluctuating resource environments and so the strength of selection on these traits is likely enmeshed in their ecological context. One such species is the leaf footed cactus bug (*Narnia femorata*), in which males use enlarged hind leg weapons to defend access to ephemeral cactus fruit food resources and secure mating opportunities. To test the effects of resource variation on sexual selection in this species, we tracked the mating interactions and locations of groups of eight individually marked

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males and females in replicated semi-natural enclosures, constituting either resource-rich (containing 6 cactus fruits) or resource-poor (a single fruit) environments. We found that, over a 5-day period, *N. femorata* gravitated towards cactus fruit, generating marked differences in the spatial clustering of individuals and mating events across the two resource treatments. Despite this, male and female mating success and female reproductive output across the two resource levels remained surprisingly similar. Continuing to explore the role of environmental resource variation is crucial to understanding sexual selection and mating system dynamics, both in this species and more widely.

68-3 Gresham, JD*; Earley, RL; Emory University , University of Alabama; *jdgresh@emory.edu*

Fecundity and self-compatibility variation among lineages and across ontogeny in a self-fertilizing fish

Mixed mating strategies offer the benefits of both self-fertilizing one's own eggs (selfing) and outcrossing, while limiting the costs of both methods. The economics of mixed mating is further determined by the individual's level of self-compatibility. Individuals that are more self-compatible can exploit the benefits of selfing when the costs of outcrossing are high, perhaps better than individuals with less self-compatibility. In gynodioecious (hermaphrodites and females) and androdioecious (hermaphrodites and males) species, the level of self-compatibility of the hermaphrodites also acts as a selection pressure on the fitness of the other sex. The mangrove rivulus fish is an androdioecious species and populations are comprised of selfing hermaphrodites and males that result from hermaphrodites changing sex. Although hermaphrodites overwhelmingly reproduce through internal selfing, they occasionally oviposit unfertilized eggs. Males can externally fertilize these eggs, resulting in outcrossed progeny. Here, we reveal that fecundity and self-compatibility varies within individuals across ontogeny and among individuals derived from lineages that vary in their propensity to change sex. Hermaphrodites from high sex changing lineages were significantly less fecund and self-compatible than hermaphrodites from low sex changing lineages. We also demonstrate that fecundity and self-

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compatibility change across ontogeny from sexual maturity to about 365 days post hatch. These differences in self-compatibility and fecundity have the potential to drive evolutionary changes on mating strategy and the fitness of males in populations of the mangrove rivulus. This study also illustrates the importance of including lineage variation when estimating the costs and benefits of mixed mating strategies.

44-3 Greville, LJ*; Bueno, LM; Pollock, T; Faure, PA; McMaster University, Department of Psychology, Neuroscience & Behaviour, University of São Paulo, Virology Research Center; *grevillj@mcmaster.ca*

Quantification of urinary sex steroids in the big brown bat (Eptesicus fuscus)

Endocrine studies on small mammals typically use blood draws for plasma analysis. However, in larger mammals urinary steroids can be used to track an individual's reproductive state. Urinary steroid analysis can also be ideal for smaller animals as it is non-invasive and allows for repeated testing. Big brown bats (*Eptesicus fuscus*) are small insectivores that have an annual reproductive cycle. As such, repeated blood draws are not ideal for the species; however, the use of a captive breeding colony provides the opportunity for repeated urine collection. The present study aimed to quantify endogenous levels of unconjugated 17beta-estradiol (E_2) via urinary analysis in male and female big brown bats. Urine was quantified as unadjusted steroid measurements as well as creatinine-corrected values to control for animal hydration and activity levels. We observed differences in urinary E_2 between male and female adults, as well as age effects in males. A number of seasonal differences in both creatinine-adjusted and unadjusted urinary E_2 were observed in males and non-pregnant females. We also explored seasonal differences in urinary progesterone (P_4) levels in non-pregnant female bats across seasons. The highest values of urinary steroids were measured in pregnant female bats were both E_2 and P_4 peaking ~20 days prior to parturition. This project is the first to monitor urinary steroids across the reproductive cycle in bats, and is the first step towards using urinary steroids to detect pregnancy in bats. Importantly, the quantification of

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urinary steroid levels is critical in interpreting their role as possible reproductive pheromones in bats.

72-10 Griffin, B*; Martin-Silverstone, E; Demuth, O; Palmer, C; Rayfield, EJ; University of Bristol; *ben.griffin@bristol.ac.uk*
Constraining quadrupedal launch: Range of motion in Coloborhynchus robustus
Constraining Quadrupedal Launch: Range of Motion in *Coloborhynchus robustus* B Griffin[1], E Martin-Silverstone[1], O Demuth[1], C Palmer[1], E J Rayfield[1] [1] University of Bristol ben.dinosaur@gmail.com
Pterosaurs reached sizes significantly larger than any modern flyer and as a result there is uncertainty whether the largest pterosaurs were capable of flight. The quadrupedal launch hypothesis proposes that pterosaurs circumvented the size restriction seen in modern flyers by using their fore- and hindlimbs to generate sufficient thrust to propel the body into the air during take-off. Here we investigate the ability of the mid-sized ornithocheirid *Coloborhynchus robustus* to assume the poses required to utilise the quadrupedal launch hypothesis. We applied range of motion (ROM) mapping methodology to the pelvic and pectoral girdles to identify unviable poses at varying levels of appendicular cartilage based on an extant phylogenetic bracket model. The ROM of each girdle were further constrained by utilising the novel Triangulated Minimum Stretch (TMS) methodology, identifying the connective tissue constrained ROM. We found that the pelvic girdle could assume the required poses for quadrupedal launch, requiring offset from appendicular cartilage equivalent to an ostrich, while the pectoral girdle requires appendicular cartilage equivalent to modern alligators. The connective tissue ROM for the pelvic girdle found that the poses required for quadrupedal launch could be reached with low levels of ligamentous stretch. The pectoral girdle investigation revealed the poses required for quadrupedal launch could be reached with muscular stretch values equivalent to modern birds. Our study indicates that *Coloborhynchus robustus* would be capable of assuming the poses required to launch utilising the quadrupedal launch hypothesis.

46-7 Griffin, RA*; Boyd, A; Blewett, TA; University of Alberta,

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Feeling a little crabby from hunger: branchial amino acid uptake in arthropods

Many aquatic species are known to be extremely successful at invading in non-native waters, due to their ability to thrive under a wide variety of environmental factors. Therefore, understanding the physiological advantages invasive species may have over native species gives insight into the differences of fitness allowing them to outcompete. It has recently been shown that the green shore crab (*Carcinus maenas*) has the ability to uptake nutrients, in the form of amino acids (e.g. L-Leucine), through its gills from the surrounding environment. However, it was previously unknown how many other species of crustacean are capable of environmental nutrient uptake, and what the implications of changing environmental factors may have on nutrient uptake rates. Dissolved nutrient acquisition in *Carcinus maenas*, *Metacarcinus gracilis*, *Cancer magister*, and *Cancer productus* were evaluated using in vitro gill perfusion to conduct kinetic nutrient transport assays with the amino acids L-leucine and L-alanine. When compared to the native species, the invasive *Carcinus* displayed uptake kinetics of a high capacity and high affinity transporter. This research investigates the importance of this nutrient pathway in the invasive success of *Carcinus* and determines if dissolved nutrient acquisition is unique to *Carcinus* or if it can be found across various crustacean species.

BSP-11-2 Griffing, AH*; Sanger, TJ; Gamble, T; Marquette University, Milwaukee, WI, Loyola University in Chicago, Chicago, IL; *aaron.griffing@marquette.edu*

Investigating serial homology of the adhesive structures of diplodactylid lizards (Reptilia: Gekkota)

One goal of evolutionary developmental biology (evo-devo) is to understand the role of development in the origin of phenotypic novelty and convergent evolution. Geckos are an ideal system to study this topic as they are species-rich and exhibit a suite of diverse morphologies - many of which have independently evolved multiple times within geckos. Classic examples of such morphologies are adhesive toepads, which have been gained and lost at least 12 and seven times, respectively, through gecko evolutionary history.

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Crested geckos (*Correlophus ciliatus*) not only exhibit impressive adhesive toepads, but also an adhesive pad located at the tip of their prehensile tails. Although *C. ciliatus* was presumed extinct before being rediscovered in 1994, this species is now abundant in the pet trade, providing the ideal opportunity to study the development of these remarkable structures. Due to the overall differences in adult morphology between *C. ciliatus* toepads and tailpads, we hypothesized that the adhesive tailpads of *C. ciliatus* are not serial homologs of toepads; therefore, we predicted that tailpads would exhibit different morphological and temporal developmental patterns to those of toepads. To test this hypothesis, generated embryonic series of *C. ciliatus* and *Lepidodactylus lugubris*, a non-adhesive-tailed gecko. We visualized tail and toepad development using scanning electron microscopy (SEM). Early development of *C. ciliatus* tailpads is similar to that of toepads but rapidly diverges from this pattern through the formation of granular scales. Here, we discuss evidence for the serial homology and novel scale formation of adhesive tailpads and discuss development of adhesive structures in a phylogenetic context.

76-6 Grimes, CJ*; Labonté, JM; Lopez, JV; Schulze, A; Texas A&M University at Galveston, Nova Southeastern University; *grimes@tamu.edu*

Pass me the microbes, please! Bearded fireworms source part of their microbiome from bleached and healthy corals and vice versa

Microbiomes have come into focus for the study of coral reef health and disease dynamics because their health and decline are tightly coupled to their microbiome. Many coral diseases have been attributed to pathogenic bacteria, but vectors for these bacteria are still largely unstudied. The epidermis of the corallivorous bearded fireworm, *Hermodice carunculata*, has been shown to be a vector and reservoir for the pathogen *Vibrio shiloi*, causing bleaching in *Oculina patagonica* corals in the Mediterranean. Considering the increasing incidence and severity of coral diseases in the Caribbean, we investigated the transfer of microbes, including pathogenic and potentially probiotic taxa, with microbial ecology sequencing (16s ribosomal RNA) techniques between coral colonies and selected body parts (prostomium, pharynx, gut, whole

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worm samples) and feces of *H. carunculata*. Our results show that *Vibrionaceae*, a bacterial family containing known bleaching pathogens, is present in relatively high relative abundance in the whole worm samples (~30%) and the bleached great star coral, *Montastrea cavernosa* (~10%). We saw a similar relative abundance for the bacterial families *Alteromonadaceae* and *Saccharospirillaceae* in the fireworm's prostomium and fire coral, *Millepora* sp. Our statistical analyses suggest the fireworm digestive tract (pharynx, gut, and feces) both acts as a sink for pathogenic bacteria from bleached *M. cavernosa* and a source to seemingly healthy *M. cavernosa*. These findings suggest that not only may the epidermis serve as a reservoir for pathogens, the digestive tract and pharynx in particular serve as a point of transmission between the fireworm and its healthy coral prey.

109-1 Grosiak, M*; Koteja, P; Bauchinger, U; Sadowska, ET; Jagiellonian University, Institute of Environmental Sciences, Krakow, Poland ; *marta.grosiak@doctoral.uj.edu.pl*

Thermoregulatory properties of bank voles affected by age and artificial selection

As many performance traits, the capacity of endotherms to thermoregulate declines with age. Aging compromises both the capacity to conserve or dissipate heat and the thermogenesis, which is fueled by aerobic metabolism. Therefore, we hypothesized that selection for an increased aerobic exercise metabolism affects both the thermoregulatory traits and the age-related changes of these traits. This was tested on bank voles (*Myodes glareolus*) from an experimental evolution model system: lines selected for high swim-induced aerobic metabolism (A lines), which have also increased the basal and maximum cold-induced metabolic rates, and unselected (C) lines. We measured the resting metabolic rate (*RMR*), evaporative water loss (*EWL*) and body temperature in young adult and old voles at seven ambient temperatures (13 to 32° C). The *RMR* was 6% higher in A than C lines, but did not change with age. However, *EWL* was 12% higher in the old voles. An increased *EWL/RMR* ratio implies either a compromised efficiency of oxygen extraction in lungs or increased skin permeability. This effect was more profound in the A lines possibly due to in-line voles than in those from other

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groups. The thermogenic capacity (the maximum cold-induced oxygen cocreased vulnerability to aging. Only at 32° C body temperature was markedly higher in the old A-line voles than in those from other groups. The thermogenic capacity (the maximum cold-induced oxygen consumption) was decreased by about 13% in the old voles from both selection groups, but the performance of old A- and young C-line voles was similar. Thus, the selection for high aerobic exercise metabolism attenuated the adverse effects of aging on cold tolerance, but this advantage is traded off by a compromised coping with hot conditions by aged voles. Funded through NCN grant 2016/22/E/NZ8/00416 to ETS.

110-8 Gross, D*; Davoll, ME; Freehill, D; Nelligan, N; Benton, B; Larouche, O; Loganathan, A; Weller, HI; Williams, K; Price, SA; Clemson University, Rice University, Brown University; *sprice6@clemson.edu*

A mouthful of fry and eggs: does mouth-brooding influence head and body shape evolution in cichlid fishes?

Cichlidae, a diverse family of fishes, have repeatedly evolved a specialized form of parental care known as mouthbrooding, where parents protect their eggs or fry in their mouth. Some mouthbrooders have evolved larger, elongated heads in order to maximize buccal cavity volume, to allow the largest brood possible, while also maintaining hydrodynamic efficiency and respiratory function. We therefore hypothesized that cichlids with different parental care behavior will also differ morphologically. Based on a previous study in Lake Tanganyikan cichlids we also predicted that rates of shape evolution would be slower in mouthbrooding cichlids. We compared the effect of parental behavior on morphology in 62 African and 99 South American cichlid species. Data on parental care were gathered from FishBase and the literature. We quantified body and head shape variation on preserved specimens using two distinct methods, traditional linear measurements and geometric morphometrics. Phylogenetic comparative methods were used to test for significant differences in head and body shape, disparity, and rates of evolution between species with different parental behavior. Preliminary results opposed our initial predictions, revealing few shape differences among parental care types and showing that the rate of morphological evolution is significantly

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faster in mouthbrooders, whereas disparity is greater in non-mouthbrooding species.

52-2 Grossnickle, DM*; Brightly, WH; Law, CJ; Pevsner, SK; Roston, RA; Stanchak, KE; Weaver, LN; University of Washington, University of Bristol; *davegrossnickle@gmail.com*

Testing the prevalence of morphological convergence among mammalian forelimb skeletons

Identifying morphological convergence is important for understanding adaptive evolution because it shows that distantly related organisms can evolve similar structural solutions to ecological problems. However, the extent to which ecologically-driven convergence can overcome distinct evolutionary histories is unclear. The mammalian forelimb is frequently used as an example of convergent evolution because mammals with similar locomotor strategies often exhibit similar skeletal morphologies. Here, we use forelimb measurements from 201 mammalian species to examine the prevalence and strength of morphological convergence among locomotor modes and to test whether convergence is more pronounced among locomotor specialists than among generalists. We employ evolutionary model-fitting analyses and two metrics of convergence. Our results indicate that incomplete convergence is more prevalent than complete convergence, suggesting that ecologically-driven convergence does not overcome distinct evolutionary histories. Further, our results do not support the hypothesis that locomotor specialists (e.g., subterranean fossorialists and gliders) demonstrate greater morphologically convergence than generalists (e.g., terrestrialists and arborealists). These results highlight that although mammals with specific locomotor modes tend to share some skeletal traits, phylogenetic inertia and functional tradeoffs unaccounted for by discrete ecological categories maintain morphological differences and prevent complete convergence.

92-5 Güell, BA*; Gomez, EK; Warkentin, KM; Boston University; *bguell@bu.edu*

Gliding treefrog reproduction: Possible functions of diverse male behavior in terrestrial breeding aggregations

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Gliding treefrogs, *Agalychnis spurrelli*, on Costa Rica's Osa Peninsula breed explosively in huge aggregations with highly male-skewed sex ratios and intense male-male scramble competition. We have observed multiple males cluster around females in attempts to dislodge amplexed males or clasp pairs before and during oviposition. In addition, some non-clasping males position their vents directly beside females' during oviposition and others kick at recently laid eggs, including after pairs leave. Egg-kicking has been hypothesized to be an antagonistic strategy to remove and kill competitors' offspring. To test this hypothesis, we assessed whether the male behavior of kicking at egg masses dislodges eggs from them by analyzing video recordings of *A. spurrelli* in the wild. We analyzed 754 kicks by 57 different males at 47 egg masses, across nine reproductive events and two breeding seasons. Kicking never dislodged the affected eggs, regardless of duration or number of kicks. Our findings suggest that this male egg-kicking behavior serves another purpose and requires further investigation. We hypothesize that clasping amplexed pairs, vent-positioning adjacent to pairs, and egg-kicking function as alternative reproductive tactics in which non-amplexed males fertilize eggs by sperm competition or inseminating remaining unfertilized eggs. Our current work combines behavioral data from video recordings with genetic parentage analysis to assess the function and associated reproductive success of these behaviors. If, as it appears, *A. spurrelli* exhibit multiple reproductive tactics, this work will create new opportunities for research on reproductive variation in explosive-breeding tropical frogs with terrestrial eggs and may have implications for understanding reproductive systems more broadly.

42-9 Guindre-Parker, S*; Rubenstein, DR; Kennesaw State University, Columbia University; *sguindre@kennesaw.edu*

The oxidative costs of unpredictable environments

Climate change is expected to increase the frequency of unpredictable weather in many parts of the world, and understanding how organisms will fare under this unpredictability is key. Unfortunately, little is understood about how living in environments that fluctuate unpredictably over time shapes individual condition. We will explore how oxidative stress—the

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imbalance between harmful reactive oxygen species and neutralizing antioxidants—differs across populations of superb starlings (*Lamprotornis superbus*) found across a range of different environments. We sampled free-living starlings across 8 populations in Kenya that experience different degrees of unpredictability in precipitation among years, where precipitation is a key driver of insect and food availability. We will explore the relationships between reactive oxygen metabolites, antioxidants, and oxidative balance, as well as whether oxidative balance is shaped by short-term deviations from total annual precipitation or long-term unpredictability in precipitation. Our preliminary results suggest that individuals in less predictable environments experience greater oxidative stress. We will discuss the implications of our results for how unpredictable environments may affect organisms in a rapidly changing world.

40-6 Gumm, JM*; Stanton , MR; Feuerbacher, OG; US Fish and Wildlife Service; *jennifer_gumm@fws.gov*

Growth rates and morphology of wild, refuge and lab derived Devils Hole pupfish (Cyprinodon diabolis)

Devils Hole pupfish (*Cyprinodon diabolis*) are morphologically distinct from closely related species by having a smaller body size with a large head and lacking pelvic fins. Manipulative experiments in closely related species have established a proposed mechanism for their morphological differences and have shown that environmental variables, specifically high temperatures and limited food availability, have effects on hormones and growth leading to vastly differing morphologies. The Ash Meadows Fish Conservation Facility houses a captive population of the endangered Devils Hole pupfish in a 100,000-gallon refuge tank designed to mimic the extreme desert habitat and ecosystem of Devils Hole. It is well established that environmental parameters contributed to altered morphology and behavior of *C. diabolis* in past refuge populations, but the population at Ash Meadows is exposed to less environmental variation. Herein, we capitalize on breeding events in the refuge environment and in a lab environment to compare growth rates and morphology of larval and juvenile fish to those derived from wild collected eggs. We also compare data from *C. diabolis* to previous studies on closely related species to tease apart environmental vs

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genetic effects on morphology. Understanding early patterns of growth may provide insight to morphological changes in adulthood that are important considerations in management of the captive population.

61-9 Gunderson, AR; Tulane University; *agunderson@tulane.edu*
Understanding phenotypic plasticity through the lens of George Gilchrist's many contributions to the field
George Gilchrist made innumerable contributions to evolutionary biology and ecology through his research, mentorship, and service to the National Science Foundation. I will highlight all of these dimensions of George's work through the example of his impact on my own development as a scientist and the arc of my research program. In particular, I will focus on the evolutionary ecology of thermal plasticity, a field of great interest to George to which he made many significant advances. I will cover the following themes: 1) how thermal plasticity evolves at broad spatial scales, 2) the benefits of plasticity in dynamic environments, and 3) constraints on the expression and evolution of plasticity.

62-8 Gupta, P*; Vishnudas, CK; Robin, VV; Dharmarajan, G; University of Georgia, Athens, Indian Institute of Science Education and Research Tirupati, Mangalam, India; *biopooja@gmail.com*
Host phylogeny matters: Examining sources of variation in infection risk by blood parasites across a tropical montane bird community in India
Emerging infectious diseases are one of the greatest challenges of our times, with detrimental effects across scales of biological organization. Avian malaria (AM), a vector-borne disease caused by haemosporidian parasites (e.g. *Plasmodium* and *Haemoproteus*) - is an important emerging disease in bird populations globally. Large-scale mortalities have occurred in island bird communities (e.g. Hawaii and New Zealand), where AM has been recently introduced. Here, we elucidate host ecological traits that influence AM infection risk among host communities inhabiting the Sky Islands of the Western Ghats, a global biodiversity hotspot. We sampled 1177 birds (28 species) and amplified parasite mitochondrial cytochrome

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b gene (480bp) to identify AM parasites. We examined seven species-specific and four individual level ecological predictors using Bayesian phylogenetic mixed effect models and tested the effect of host phylogeny on variation in AM risk by estimating phylogenetic signal. We found 24 species infected with AM parasites (41.6% prevalence). Host ecological traits promoting parasite exposure (e.g., sociality, foraging strata and elevation) and traits affecting host susceptibility (e.g., sexual dimorphism, individual body condition and host phylogeny) influenced variation in AM risk but the relative importance of these effects varied for *Plasmodium* and *Haemoproteus*. Identifying eco-evolutionary factors affecting disease dynamics are crucial for understanding disease transmission, predicting disease risk and biological conservation.

2-12 Gurr, SJ*; Trigg, SA; Vadopalas, B; Roberts, SB; Putnam, HM; University of Rhode Island, University of Washington ; *samuel_gurr@uri.edu*

Environmental learning' in a tolerant commercial clam; Insights from phenotypic and subcellular adjustments to hypercapnic seawater

Moderate oxidative stress is a hypothesized driver of stress tolerance and lifespan extension. Whereas thermal stress, irradiance, and dietary restriction show evidence of dose-dependent benefits for many taxa, stress acclimation remains understudied in marine mollusks, despite being threatened by ocean acidification. To test for life-stage and stress-intensity dependence in eliciting enhanced tolerance under subsequent stress encounters, we initially conditioned pediveliger Pacific geoduck clam (*Panopea generosa*) larvae to (i) ambient and moderately elevated pCO_2 for 110 days, (ii) secondarily applied a 7-day exposure to ambient, moderate, and severely elevated pCO_2, followed by 7 days in ambient conditions, and (iii) implemented a modified-reciprocal 7-day tertiary exposure to ambient and moderate pCO_2. Initial conditioning to moderate pCO_2 stress followed by secondary and tertiary exposure to severe and moderate pCO_2 stress increased respiration rate, organic biomass, and shell size suggesting a stress-intensity-dependent effect on energetics. Additionally, stress-acclimated clams had lower antioxidant capacity compared to clams under initial ambient

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conditions, supporting the hypothesis that stress over postlarval-to-juvenile development affects oxidative status later in life. We posit two subcellular mechanisms underpinning stress-intensity-dependent effects on mitochondrial pathways and energy partitioning: i) stress-induced attenuation of mitochondrial function and ii) adaptive mitochondrial shift under moderate stress. Time series and stress intensity-specific approaches can reveal life-stages and magnitudes of exposure, respectively, that may elicit beneficial phenotypic variation.

28-8 Gusmão, LC*; Rodríguez, E; American Museum of Natural History, New York, NY; *Gusmaolc@gmail.com*

Evidence of a deep-sea, Antarctic lineage of burrowing sea anemones (Cnidaria: Actiniaria): an evaluation using mitogenomics

Burrowing sea anemones have a simple morphology with an elongate body and a round aboral end that anchors the animal into the sediment leaving only the tentacle crown exposed. Despite the general polyphyly of burrowers within Actiniaria (formerly athenarians), a monophyletic clade of burrowing anemones has been recently discovered in Antarctica (*Scytophorus* + *Halcampulactis*+ *Halcampoides*). Based on phylogenetic analyses using nuclear and mitochondrial markers (12S, 16S, 18S, 28S, COIII) as well as morphology and cnidae, this clade has been putatively classified within Actinostoloidea but its position is unstable and support is low. Superfamily Actinostoloidea is the second most speciose in Antarctica, having a long and complex taxonomic history with more than half of its genera narrowly defined and monotypic. This pattern may be the result of relictual distributions shaped by glacial periods, colonization of the Southern Ocean several times at different periods or independently from different ocean basins at the same time, or polar emergence from the deep sea following the retreat of multiyear sea ice in interglacial periods with subsequent speciation in the Antarctic shelf. To improve resolution and help to establish the position of the recently discovered deep-sea, Antarctic lineage of burrowing sea anemones, we generated complete mitogenomes for five actinostoloideans, including three representatives of this clade, and combined them to the 29 available sea anemone mitogenomes. Based on our ML phylogenetic reconstruction for the Order

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Actiniaria, we evaluate the position of the clade in question, the resurrection and circumscription of family Halcampoididae to accommodate it, and implications for the evolution of burrowing sea anemones.

25-12 Gutherz, SB*; O'Connor, PM; Ohio University; *sgutherz0819@gmail.com*

Postcranial skeletal pneumaticity in Accipitriformes

Postcranial pneumaticity, infiltration of bones by pneumatic epithelium, is a feature unique to birds among extant tetrapods. Previous research examined variation in pneumaticity in select, generally aquatic, avian groups. These studies demonstrated that both body size and locomotor behavior (e.g. sub-surface diving, soaring) account for a proportion of the interspecific variation. This study focuses on Accipitriformes (hawks, eagles, vultures), a widespread neoavian group that spans a large range in body size and occupies a diversity of ecological niches. We sampled 91 species, capturing most of the phylogenetic, morphological and behavioral diversity of the clade. Skeletal specimens from museum collections were examined for osteological correlates of pneumaticity, with bones for each specimen scored based on the presence/absence of foramina communicating with large internal chambers. The survey revealed both phylogenetic and behavioral signals. All sampled individuals exhibited pneumaticity in the following bones: all postaxial, non-caudal vertebrae, dorsal/sternal ribs, sternum, coracoid, coxal elements and the humerus; whereas the furcula and femur were pneumatic in all but one species. Regression analyses revealed a positive, but non-significant, trend between pneumaticity and body mass. One significant point is that all members of both Old and New World vultures, distantly related groups that employ static soaring, exhibited pneumatic distal forelimbs (all bones distal to the humerus). This is a particularly rare phenotype among extant birds. Our results are consistent with previous clade-centric surveys, although Accipitriformes generally display less variability in the expression of pneumaticity than that observed in aquatic/semi-aquatic groups.

53-9 Gutierrez-Pinto, N*; Londoño, GA; Chappell, MA; Storz, JF;

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A test of altitude-related variation in aerobic metabolism of Andean birds

Endotherms at high altitude face the combined challenges of cold and hypoxia. Cold increases thermoregulatory costs, and hypoxia may limit both thermogenesis and aerobic exercise capacity. Consequently, in comparisons between closely related highland and lowland taxa, we might expect to observe consistent differences in basal metabolism (BMR), maximal metabolism (MMR), and aerobic scope. Broad-scale comparative studies of birds reveal no association between BMR and native elevation, and altitude effects on MMR have not been investigated. We tested for altitude-related variation in aerobic metabolism in 10 Andean passerines representing five pairs of closely related species with contrasting elevational ranges. Mass-corrected BMR and MMR were significantly higher in most highland species relative to their lowland counterparts, but there was no uniform elevational trend across all pairs of species.

55-1 Habegger, ML*; Bright, J; University of North Florida, University of Hull; *mlaurahabegger@unf.edu*

The predentary bone and its role in feeding in billfishes

Billfishes are characterized by the elongation of their upper jaw into a bill or rostrum, this structure has a relevant role in feeding. Differences in rostrum morphologies have been linked to a range of different feeding behaviors and biomechanics. While the role the rostrum plays in prey processing has been thoroughly investigated, our understanding of the morphology and biomechanics of other feeding structures is less understood. The morphology of the lower jaw in billfishes is diverse among species, and one of the most interesting characteristics is the presence of the predentary, a distal bone unique to Istiophoridae (marlins and sailfishes) but absent in all extant fishes including their sister group, Xiphidae (swordfishes). We investigated the role of the predentary in billfish feeding using Finite Element Analysis, hypothesizing that the predentary reinforces the symphysis of the more robust istiophorid jaws to prevent torsion and "wish boning", thus allowing Istiophorids to withstand the larger bite forces they

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are known to exert relative to the Xiphiids. Finite Element models of the lower jaws of multiple billfish species were constructed from CT scans, and Von Mises stresses were compared. Different predentary morphologies, predentary presence and absence and bite force based loading regimes were compared. Results show lower stresses along the lower jaws of the blue marlin during unilateral loading, indicating that the predentary could help resist torsion. Indeed, virtual removal of the predentary bone modified the patterns of lower jaw stress. The functional implications of the predentary, in addition to other morphological differences between the lower jaws among billfishes, give further insight in to the differences in the group's feeding biomechanics and behaviors.

S5-11 Hager, ER*; Kingsley, EP; Harringmeyer, OS; Hoekstra, HE; Harvard University; *ehager@fas.harvard.edu*

Genetics and function of repeatedly-evolved tail length differences in deer mice

Determining both the genetic causes and the functional consequences of morphological variation is critical to understand how organisms adapt to their local environment. Like a number of other rodent taxa, deer mice (*Peromyscus maniculatus*) that live in forested habitat have evolved longer tails than prairie mice of the same species. This difference evolved separately at least twice, in eastern and western North America. Differences in tail length are proposed to improve performance during arboreal locomotion; testing such functional hypotheses is critical to understand adaptation. Here, using two replicate forest-prairie subspecies pairs, we tested both the genetic and developmental mechanisms that underlie the longer tails of forest mice, and the functional consequences of the tail length difference for balance. We found that forest deer mice consistently perform better in a simple assay of arboreal locomotion, even when reared in the lab and naïve to climbing. In both eastern and western subspecies, genetically and developmentally independent changes in vertebra length and number contribute to the longer tails of forest mice. Despite these highly parallel phenotypes, we found that the underlying causative alleles are likely at least partly distinct in eastern and western subspecies. Finally, we used hybrid, laboratory-reared populations alongside simple analytical models to test the functional

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significance of tail length; using this approach, we found that the inter-population and inter-individual differences in tail length may contribute to performance. By addressing both the genetic causes and functional consequences of parallel evolution within species, this work provides insight into the mechanisms of local adaptation.

10-4 Hagey, TJ*; Pillai, R; Riedel, J; Schwarzkopf, L; Mississippi University for Women , James Cook University ; *thagey@muw.edu*

3D imaging of the lizard adhesive system via photogrammetry

Nature has harnessed nanotechnology to generate a variety of specialized smart materials which include antifouling, adhesive, hydrophobic, hydrodynamic, and antibiotic properties. A basic first step in understanding nature's micro and nano-scale structures is the ability to visualize and image these very small yet complex structures easily and accurately. This can be a difficult endeavor. Electron microscopy is a common high-resolution imaging approach, with magnifications over 50,000X, yet electron microscopy can suffer from optical distortions and is typically limited to 2D images. In order to produce accurate 3D models of micro and nano-scale structures, I am developing an approach to combine electron microscopy with a 3D photogrammetry, which uses a collection of 2D images to produce a 3D reconstruction. Scanning election microscopy has the necessary resolution and is readily available. Data collection for photogrammetry is straight forward and also inexpensive. To investigate the use of photogrammetry to digitally reconstruct scanning electron microscopy images, I will focus on naturally occurring, complex, adhesive structures from gecko toe pads. These structures represent an amazing natural example of nanotechnology. Geckos (and other pad bearing lizards) use a wide variety of surfaces in the wild. Gaining a better understanding of their adhesive morphology is an exciting first step to better understanding how species are adapted to specific scansorial microhabitats. Investing adaptive patterns and biomechanics of the gecko adhesive system is also relevant for the production of synthetic gecko-like adhesives, currently an active area of biomimicry research.

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69-7 Hainer, JC*; Maki, H; Lutek, K; Znotinas, KR; Standen, EM; University of Ottawa; *jhain006@uottawa.ca*

ViscoSenso: The role of multiple sensory modalities in steady swimming

The amphibious fish *Polypterus senegalus* is able to traverse both aquatic and terrestrial environments. Because of their locomotor flexibility, they are also able to adapt their behavior when exposed to a novel aquatic environment, such as increased mechanical resistance in the form of viscous water. When exposed to this environment we observed an "exaggerated" form of steady swimming. We hypothesize that sensory feedback from the lateral line and visual systems in *P. senegalus* is used to modulate swimming kinematics in a viscous environment. We removed lateral line and visual input independently and in combination to assess the relative importance of the sensory systems in normal and high viscosity. Using high speed video, we measured changes in swimming kinematics and behaviour. Increased viscosity resulted in an increase in magnitude of body amplitude, wave frequency and wave speed, while overall swimming speed was maintained. Lateral line and visual systems were each able to compensate for a lack of sensory feedback from the other. A lack of sensory feedback across both sensory systems lead to an increase in the amplitude of measured kinematic variables and swim speed, possibly as an attempt to increase sensory input. Mechanical constraint due to high viscosity eliminated the performance outcome of this increase in kinematics. Absence of lateral line and visual sensory feedback did not impede the steady swimming performance of *P. senegalus* in viscous water, suggesting that some other sensory modality is of greater importance in this environment. Extreme environments may limit the functional importance of certain sensory systems, dampening their effects on swimming form.

75-1 Hale, ME*; Paletta, MG; University of Chicago, Chicago, IL ; *mhale@uchicago.edu*

The water to land transition, submerged: How octopuses and other animals integrate movement on substrate and in water to locomote in aquatic environments

Animals use a variety of gaits to locomote. For most species, a change in gait involves use of different movement in the same

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medium -e.g. switching from trotting to galloping in horses or paired fin to axial swimming in fishes. Some species switch gaits by also changing their physical environment for movement. Best known are birds that transition between terrestrial gaits and flight. For aquatic organisms, gait transitions analogous to those of birds occur in a range of animals that can locomote on the bottom substrate and swim. Here, we examine the walking and jetting and the walk-to-jet gait transition of young California two-spot octopus, *Octopus bimaculoides*. At low speeds, octopus use their arms to walk on the bottom substrate. Our data indicate that at faster walking speeds, water pumped from the siphon augments arm-based force generation to facilitate walking, particularly in the backward direction and to the side. The transition from walking to jet-based swimming occurred when animals were walking backward in the direction of the position four arms. In the transition to fully jet-driven swimming, right four and/or left four arms frequently were the last planted and appeared to push off at the initiation of swimming. During jet-based swimming, the arms extended together trailing the body. At the end of swimming, animals frequently initiated substrate contact with one arm before splaying the others and initiating substrate-based walking. Understanding this very different and independently evolved gait transition and comparing it to locomotion in other animals provides insight into the evolution of gait use and coordination and informs investigation of the neural control of movement.

17-7 Hall, JM*; Mitchell, TS; Thawley, CJ; Stroud, JT; Warner, DA; Auburn University, University of Minnesota, Neumann University, Washington University; *jmh0131@auburn.edu*

Adaptive seasonal shift towards investment in fewer, larger offspring

As reproductive seasons progress, females often shift from greater energetic investment in many small offspring towards investing less total energy into fewer, better provisioned offspring. Two primary hypotheses have been proposed as explanations. One is an adaptive hypothesis from life-history theory: early offspring have a survival advantage over those produced later. Accordingly, selection favors females that invest in offspring quantity early in the season and offspring quality later. The other suggests these

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patterns result from passive responses to seasonal changes in the environment experienced by reproducing females. To disentangle the causes underlying this pattern, we performed complementary field and laboratory studies with lizards (*Anolis sagrei*). The laboratory study controlled maternal environments and quantified reproductive patterns throughout the reproductive season for each female. The field study measured similar metrics from free ranging lizards across an entire reproductive season. In the laboratory, females increased relative effort per offspring as the reproductive season progressed; smaller eggs were laid earlier, larger eggs were laid later. Because these patterns consistently emerge under controlled laboratory conditions, they likely represent an intrinsic, potentially adaptive adjustment of reproductive effort as predicted by life-history theory. The field study revealed similar trends, suggesting that intrinsic patterns are strong enough to persist despite the environmental variability that characterizes natural habitats. The observed patterns are indicative of an adaptive seasonal shift in parental investment in response to a deteriorating offspring environment: allocating greater resources to late-produced offspring likely enhances maternal fitness.

21-6 Hall, LM*; Mensinger, AF; University of Minnesota-Duluth; *hall1722@d.umn.edu*

Effects of boat motor sound on bluegill sunfish (Lepomis macrochirus) nesting behavior

Although anthropogenic activity and sound levels have been increasing in freshwater ecosystems, their effect on freshwater species is relatively unexplored. Boat motor sound is a prominent stimulus that the recreational use of lakes adds to the freshwater soundscape. Bluegill sunfish (*Lepomis macrochirus*) are a common target of anglers and therefore can experience frequent anthropogenic sound. To examine the effects boat motor sound has on nesting bluegills, the soundscape and fish were monitored near established nests using an underwater array equipped with a hydrophone, video camera, and underwater speaker in a lake in Makinen, MN. Nest rim circling is a prominent behavior of nesting bluegills and functions to aerate the eggs and increase vigilance. This behavior was monitored before, during, and after each sound trial. Individual nests were exposed to either shorter, frequent

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playbacks of boat motor sound (6 x 30 sec playback with 5 min intersound intervals) or longer duration, less frequent playback (3 x 5 min playback with 30 min intersound intervals). Preliminary results indicate rim circling behavior decreases during boat motor playback but that nesting bluegills do not orient towards the speaker. Any reduction in rim circling in the presence of boat motor sound could decrease reproductive fitness by compromising egg aeration and the ability of the fish to defend against intruders. Examining these behavioral responses will help investigate if sound from recreational boat use disrupts bluegill nesting behavior and may lead to boating restrictions during nesting season.

87-8 Hallas, JM*; Parchman, TL; Feldman, CR; University of Nevada Reno; *jhallas@nevada.unr.edu*

Phylogenetic and population genetic analyses of the western terrestrial garter snake (Thamnophis elegans) reveal distinct evolutionary lineages and biogeographic patterns across western North America

A central aim of biogeography is to understand how biodiversity is generated and maintained across landscapes. Here, we establish phylogenetic and population genetic patterns in a widespread garter snake *Thamnophis elegans* to quantify the influence of historical biogeography and environmental variation on patterns of genetic diversity. We used genotyping-by-sequencing to assess patterns of dispersal and vicariance across biogeographic regions using ancestral area reconstruction, and population connectivity using estimated effective migration surfaces. We also identified environmental variables potentially shaping local adaptation in regional lineages using genetic-environment association (GEA) analyses. Our analyses recovered three well-differentiated genetic groups corresponding to three subspecies (*T. e. elegans*, *T. e. terrestris*, and *T. e. vagrans*) and a general eastern to western dispersal history across western North America. Fine-scale spatial structure was explained by geographic features and potential local adaptation in both *T. e. elegans* and *T. e. terrestris*. Populations of *T. e. elegans* displayed a latitudinal gradient in genetic variation across the Sierra Nevada and northern California, while populations of *T. e. terrestris* show discrete genetic breaks consistent with well-known biogeographic barriers. GEA analyses

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suggest that local adaptation due to a common set of environmental variables has further shaped spatial patterns of genetic variation in *T. e. elegans* and *T. e. terrestris*. We recovered stark genetic differentiation among and within three subspecies of *T. elegans*. Subspecies *T. e. elegans* and *T. e. terrestris* show distinct patterns of diversification while adapting to the new environments they colonized.

101-4 Hamilton, NM*; Pence, A; Morrison, ML; Texas A&M University; *nhamilton@tamu.edu*

Predicting range shifts under future climate conditions in threated species using the Townsend's big-eared bat, Corynorhinus townsendii townsendii (Cooper, 1837), as an example organism

Effective management decisions and appropriate conservation efforts depend on knowledge of species distribution and habitat preferences. Maps generated from species distribution models are especially important in predicting present and future occurrences of endangered or threatened species. However, failing to take population level differences into account could lead to erroneous management assessments if populations are locally adapted. Refining spatial scale of analyses can improve model predictions in ways that are useful for decisions such as reserve site selection. The goal of our study was to identify range shift estimates under future climate conditions at different temporal and geographic scales using the Townsend's big-eared bat, *Corynorhinus townsendii townsendii* , as an example species. We used records from 3 years of survey data (2014-2017) to model the distribution of *C. t. townsendii* across California. Separate models were generated using all records from survey data, by sub-setting our data based on summer and winter roosting behavior, and for each of the Level III USGS ecoregions in California. We modeled the distribution of seasonally and geographically isolated populations to determine if range shifts under future climate conditions vary based on these factors. Understanding how predicted occupancy vary across time (maternity vs hibernacula) and space (different ecoregions) could be critical for helping managers and surveyors pinpoint appropriate areas to survey for *C. t. townsendii* or sites that need additional protection.

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S4-1 Hansen, AK; California State University, Fresno; *akhansen@mail.fresnostate.edu*

Introduction to the symposium: biology beyond the classroom

This symposium brings together speakers who showcase innovative approaches for engaging students in experiential science learning experiences. Specifically, we focus on three high-impact practices that allow students to take their learning outside of the classroom for increased relevance and authenticity: 1) Course-Based Undergraduate Research (CUREs), 2) Digital Fabrication in Makerspaces, and 3) Service or Community-based Learning Opportunities. Although each topic is unique, all provide an alternative approach to the traditional lecture and have proven effective at appealing to diverse groups of students who are traditionally underrepresented in the Science, Technology, Engineering, and Mathematics (STEM) workforce. Speakers from a wide range of institutions will share pedagogical best practices as well as current research investigating the efficacy of their approach for enhancing student learning and success.

89-3 Hanson, HE*; Wang, C; Zimmer, C; Schrey, AW; Liebl, AL; Ravinet, M; Jiang, RHY; Maddox, JD; Martin, LB; University of South Florida, Georgia Southern University Armstrong Campus, University of South Dakota, University of Nottingham, Field Museum of Natural History, Universidad Científica del Perú, American Public University System; *haleyhanson@mail.usf.edu*

Epigenetic potential in house sparrow (Passer domesticus) introductions

During vertebrate invasions and range expansions, organisms may rely on epigenetic modifications to endure the suite of challenges faced in new areas. However, individuals may differ in their epigenetic potential (EP), or the capacity for epigenetic modifications to occur within the genome. One form of EP, the number of CpG sites (e.g. motifs at which DNA methylation can occur), was found to differ across an ongoing house sparrow (*Passer domesticus*) range expansion in Kenya. At the vanguard of their range, birds maintained more CpG sites (higher EP) than at the site of their introduction due to selection acting to preserve CpG

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sites. To better understand the spatial and temporal dynamics of EP, we utilized museum specimens to query EP across five independent invasions 30, 50, and 100 years post-introduction. We found that house sparrows early in their invasions had the highest EP and EP decreased over time across invasions.

BSP-2-1 Harada, N*; Oura, T; Maeda, M; Shen, Y; Kikuchi, DM; Tanaka, H; Tokyo Institute of Technology, Japan, Royal Veterinary College, UK; *harada.n.ac@m.titech.ac.jp*

Kinematics and hydrodynamics analyses of flapping-wing swimming in a penguin

Penguins use the wings (flippers) to swim underwater and demonstrate excellent capability such as long-distance travel and agile maneuvers for foraging or escaping. Although previous 2-D kinematics studies depicted the basic lift-based propulsion mechanism, the details of the 3-D wing kinematics, wing deformation, and thrust generation mechanism are largely unknown. In this study, we reconstructed the 3-D kinematics of a gentoo penguin (*Pygoscelis papua*) in slow forward swimming at an aquarium using multidirectional videos recorded by twelve underwater cameras. We also conducted water tunnel experiments with a 3-D printed wing to obtain its lift and drag coefficients for various angles of attack. Combining the obtained kinematics and hydrodynamic force characteristics, the thrust of the wings was calculated in a quasi-steady manner. In the calculation, the effect of the wing deformation was evaluated by comparing the following two cases: (1) an original case where the wing kinematics include original bending deformation; and (2) a rigid case where the wing was flattened. The kinematic measurements revealed that the wings are dynamically bent in accordance with flapping, which decreases the magnitude of angle of attack during both upstroke and downstroke. Moreover, the comparison of the original and rigid cases demonstrated that greater thrust was generated in the original case, where the excess angle of attack is suppressed by the wing bending. The present study provides a qualitative mechanism of lift-based propulsion in penguins and imply the importance of wing bending on thrust generation.

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95-2 Hardy, AR*; Hale, ME; University of Chicago; *arhardy7@uchicago.edu*

Taste bud abundance and distribution on the paired fins of damselfish

Fish use taste buds in the oropharyngeal cavity as well as across the body and fins to detect dissolved organic compounds in the surrounding environment. The abundance and distribution of taste buds varies across fishes and often reflects adaptations to a particular habitat or feeding behavior. Traditionally, extraoral taste buds have been thought to be found largely in species inhabiting benthic and/or turbid environments where vision is of limited use. To investigate this idea, we examine of the abundance and distribution patterns of taste buds across the pectoral and pelvic fins of damselfish. As diurnal predators, these fishes are thought to rely on vision during feeding. They inhabit shallow, clear and light‐rich waters of coral reef environments where the utility of extraoral taste buds has not been previously investigated. Using immunohistochemical techniques, we found pear-shaped receptors across the paired fins whose morphological characteristics and specificity to the calretinin antibody are consistent with those of taste buds identified previously in other species. Taste bud density was highest along fin margins and peaked (~200/mm^2) at the distal tips of the elongated leading-edge pelvic fin rays. By mapping the full array of taste buds, we show variation in the distribution of taste buds likely reflecting differences in the functional demands for feeding across species and fins. Given the high receptor density on the paired fins of the species examined here, we suggest that damselfish fins play important chemosensory roles. These data also demonstrate that fishes inhabiting a myriad of habitats and environmental conditions utilize chemosensory feedback from taste buds outside the oral cavity.

60-4 Härer, A*; Rudman, SM; Rennison, DJ; University of California, San Diego, Washington State University; *ahaerer@ucsd.edu*

How the interaction between host and gut microbiota promotes threespine stickleback's adaptation to distinct trophic niches

The crucial role of the gut microbiota for the ecology and evolution of their hosts is becoming increasingly appreciated. Yet,

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we still lack knowledge of how the interaction between hosts and their microbial hitchhikers affects the hosts' adaptation to new niches and to what extent compositional and functional changes of the gut microbiota can be predicted. Here, we study the relative contribution of host ecology and morphology as well as abiotic and biotic characteristics of the environment in driving patterns of gut microbiota variation (based on 16S rRNA gene sequencing) within and among populations. Further, we ask whether the dietary niche width of host populations (i.e., generalist vs. specialist) is associated with variation in the gut microbiota, which might influence host trophic specialization and adaptation. We address this question in a comparative framework across eight natural populations of threespine stickleback from British Columbia, Canada, that show substantial variation in diet along the benthic-limnetic axis. The results obtained in the course of this study allow us to determine the factors, which are key to determining predictability in gut microbiota community assembly. Quantifying the magnitude of predictability is crucial for understanding how a host, its gut microbiota and the environment interact during the adaptation to different ecological niches.

106-3 Harman, TE*; Strychar, KB; Barshis, DJ; Hamsher, SE; Hauff-Salas, B; Grand Valley State University - Annis Water Resource Institute, Muskegon, MI, Old Dominion University, Norfolk, VA, Grand Valley State University, Allendale, MI, Our Lady of the Lake University, San Antonio, TX; *harmant@mail.gvsu.edu*

Ecological simulation of baseline immunity indicates potential disease susceptibility in Astrangia poculata

Global warming currently devastates corals by increasing ocean temperatures resorting to large-scale bleaching events. Coral diseases have risen alongside these in the past few decades, increasing mortality in tropical corals. As these continue, the response of corals in temperate systems are unknown. This research focuses on Astrangia poculata and how it will respond to increased temperature and disease exposure. This study examined colonies collected from Narragansett Bay located in Rhode Island to comparatively assess ambient (18 ° C) versus elevated temperatures (26 ° C) in the presence of disease (i.e. lipopolysaccharide isolated from E. coli O127:B8). This study assessed

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prophenoloxidase (PPO) and melanin via absorbance to determine A. poculata's immune response. No differences were found in PPO between symbiotic state, treatments, or season. Melanin had higher concentrations in symbiotic compared to aposymbiotic coral ($p \leq 0.05$). This study is the first to report an immune response in A. poculata. Overall, we observed low melanization across treatments indicating potential susceptibility to disease. It is plausible that parameters such as the surface mucus layer and lectins from the complement pathway may contribute to protection where the upregulation of a melanin-synthesis pathway is not necessary. Although this study introduces the plausibility of disease susceptibility in A. poculata, future studies should investigate additional parameters such as lectins to further understand the entirety of innate immunity in this temperate species.

86-3 Harrison, JF*; Wagner, JM; Aivazian, V; Duell, ME; Klok, CJ; Weed, M; Munoz, E; Vandenbrooks, JM; Fezzaa, K; Socha, JJ; Arizona State University, Argonne National Labs, Viirginia Tech; *j.harrison@asu.edu*

How to be a giant: hypermetric scaling of leg tracheal systems in cockroaches and scarab beetles suggests oxygen transport to the legs limits maximal insect size

Understanding the causes and consequences of evolution of larger or smaller body sizes in a lineage remains an important challenge in evolutionary biology. We studied how the morphology of the tracheal system varies with insect size. Based on comparisons with vertebrates, we expect either isometric scaling (as found for lungs) or hypometric scaling (as found for vertebrate capillaries), with the latter matching the hypometric scaling of metabolic rate. We tested these expectations using one-to-three individuals of ten species of cockroach, and ten species of scarab beetles; species varied by more than an order of magnitude in body mass and included some of the largest extant species. Cockroaches were imaged at Argonne National Laboratories using x-ray synchrotron imaging, while scarab beetles were imaged at Virginia Tech by microCT. We measured the fraction of body volume occupied by the tracheal system for the major body compartments. In general, the tracheal system scaled isometrically in the head, thorax and abdomen.

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However, within the legs, tracheal volume scaled strongly hypermetrically, due to an increase in the number (roaches) and size (scarabs) of tracheae and/or air sacs with size. These data strongly suggest that evolution of larger species of insects requires increased relative investment in the tracheal system of the legs to overcome the challenges of long-distance transport through these long, blind-ended structures, limiting the maximal size of insects. Supported by NSF IOS 1122157 and IOS 1558052.

41-10 Harrison, JF*; Henry, JR; Ostwald, M; Glass, JR; Arizona State University; *j.harrison@asu.edu*

Can we teach the learning objectives of an animal physiology lab online?

Teaching effectively online has many challenges, but has the potential to broaden the pool of students. For our fully-online animal physiology lab, we identified teaching objectives related to understanding: 1) how physiological transducers are used, 2) physiological studies, and 3) organ system function. The 6-7 week, two-credit online course we developed has three components. For component 1, students purchase, construct, program and use an Arduino-based system to record EMGs. They design a well-controlled experiment using their system and submit a report. In component 2, online groups collaboratively write a NSF-style proposal to study an aspect of physiology not currently understood. They must choose a topic, review literature, and define questions. Proposals include a budget and human subjects/animal use permission forms as appropriate. With a half-time TA per 50 students, it is possible to give substantial student feedback at each step of components 1 and 2. In component 3, pre-lab modules and quizzes prepare students for ten 45-min simulation labs developed in collaboration with Labster Inc. Post-lab quizzes assess understanding of the following simulation topics: thermal homeostasis and energetics, the ionic basis of action potentials, using voltage and current-clamp to understand nociceptor function, the hormonal control of reproduction , mechanics of skeletal muscle fiber types, autonomic control of smooth muscle, cardio-respiratory function during human exercise, diving physiology of Weddell seals, glucose transport by the small intestine, and renal salt and water regulation. While some hands-on skills available in our in-person lab are missed, the

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focus of the online lab is on understanding techniques of measurement and quantitative analysis. In particular, we emphasize understanding of the scientific process.

31-8 Hartwick, M*; Reichmuth, C; Thometz, N; University of San Francisco, UC Santa Cruz, Alaska SeaLife Center; *mnhartwick@dons.usfca.edu*

Using physiological measures of captive seals to inform best practices of rapid body condition assessments of wild Arctic seals

Predicting population-level responses to rapidly changing Arctic conditions requires empirical demographic and physiological data. Unfortunately, Arctic seals are particularly difficult to sample in the wild due to their remote, ice-covered habitats. Further, the ongoing Unusual Mortality Event (UME) of Alaskan ice seals—declared due to abnormally high numbers of seals stranding in poor body condition—highlights the urgent need to accurately monitor the health of wild populations. Body condition is commonly assessed in seals via blubber content and provides an important metric of individual health. As comprehensive assessments of body condition are generally not feasible to conduct during field research and subsistence activities, we evaluated the efficacy of simple metrics of body condition by comparing measurements obtained from captive seals. We used fine-scale morphometric data to calculate blubber content for one bearded (*Erignathus barbatus*), three ringed (*Pusa hispida*), and four spotted (*Phoca largha*) seals. We then ran regression analyses to evaluate how well seven different body condition metrics correlated with our comprehensive assessments of blubber content. Several simple metrics proved to be useful indicators of fat reserves. Metrics that utilized measures of blubber depth worked well across all species, while those relying on length-girth relationships were either species-specific or poor indicators. These results can refine and improve field sampling efforts and provide valuable information for conservation decision-making by management agencies as climate change continues to threaten Arctic seal populations.

BERN-1 Hau, M; Max Planck Institute for Ornithology, University of Konstanz; *mhau@orn.mpg.de*

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Hormone-mediated phenotypic plasticity: is there an optimal hormonal phenotype?
Environmental conditions fluctuate across days, seasons and years. Animals adjust to this variation by displaying plasticity in behavior, physiology and morphology, which is often mediated by hormones. Hormone-mediated phenotypic plasticity is assumed to be adaptive, yet individual variation in hormonal responses to environmental variation can be substantial and attempts to relate it to fitness have proven challenging. I will review our work on characterizing patterns of individual variation in corticosterone (the avian glucocorticoid) concentrations in wild great tit populations and associating this variation with fitness traits like reproductive success. As hormonal traits themselves are plastic, with circulating concentrations changing within minutes, we have initiated a long-term field study in which we repeatedly monitor individuals along environmental gradients. Such reaction norm approaches hold promise for determining whether average corticosterone concentrations and their degree of plasticity in response to environmental variation are individual characteristics. Since recent studies have shown that glucocorticoid traits are heritable in avian taxa, future studies that include pedigree information will enable us to quantify selection pressures on and potential microevolutionary responses in hormonal traits of wild populations to changing environments. To understand possible costs of corticosterone responses we are studying the consequences of corticosterone responses for tissue function (oxidative stress and telomere dynamics). We hope that work of this kind will help us to predict the opportunities and limitations of wild populations for coping with the ongoing anthropogenic changes in their environment.

96-1 Hauber, ME*; Winnicki, SK; Hoover, JP; Hays, IR; University of Illinois at Urbana-Champaign, Rutgers/Newark; *mhauber@illinois.edu*
The limits of egg recognition: Testing the acceptance thresholds of American robins in response to egg-shaped objects in the nest
Some hosts of avian brood parasites reduce or eliminate the costs of parasitism by rejecting foreign eggs from the nest (rejecters). In turn, even acceptor hosts remove most non-egg shaped objects from the nest, including broken shells, leaves, and other detritus. Where does a potential threshold between egg-recognition and

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detritus-rejection lie when it comes to shape? Most previous studies applied comparisons of egg-sized objects with non-continuous variation in shapes. Here, instead, we used two series of 3D printed objects, designed a priori to vary from the natural egg shape by either reducing width or increasing edge angularity. As predicted, we detected transitions from mostly acceptance to mostly rejection in the nests of American robins along these two axes of egg shape variation. Our methods parallel previous innovations in egg rejection studies through the use of continuous variation in egg coloration and maculation contrast, to better understand the limits and thresholds of egg recognition in diverse hosts of avian brood parasites.

95-10 Havens, LT*; Taylor, BK; Lohmann, KJ; University of North Carolina, Chapel Hill, Univeristy of North Carolina, Chapel Hill; *lukethavens@gmail.com*

Studying a black box: investigating processing of a receptorless sense

Phylogenetically diverse animals sense and use Earth's magnetic field for orientation and navigation, but little is known about how magnetic information is processed by the nervous system. Even with the wealth of behavioral magnetoreception data, it is difficult to study how magnetic information is processed without knowing precisely what information is encoded, and a primary magnetoreceptor has yet to be identified in any animal. Previous work has studied the transduction method of magnetoreceptive animals by subjecting them to strong magnetic pulses: if orientation behavior changes as a result of a magnetic pulse, then the magnetic field is thought to be transduced using a magnetic material such as biogenic magnetite. This disruption of behavior is because the magnetization of magnetite would be realigned after a strong magnetic pulse, similar to how a magnet can be "recharged" using a stronger magnet. Magnetic pulses inherently have a direction, however, and researchers could theoretically use this property of the existing technique to directionally ablate magnetoreceptive systems, using differences in behavioral effect between pulse angles to deduce information about the underlying system. Here we present this novel approach to investigating magnetoreception processing and test its viability using existing

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behavioral data in the Caribbean spiny lobster *Panulirus argus*. We design explanatory neural models for observed behavior and develop testable hypotheses as to how spiny lobsters may process Earth's magnetic field. Using our models we can gain insight into promising neuroanatomical targets for electrophysiological work. Our novel approach bridging the theory and behavior of magnetoreception to investigate processing appears a fruitful avenue for continued research.

17-8 Havird, JC*; Maeda, G; Zwonitzer, K; University of Texas at Austin; *jhavird@utexas.edu*

Selection (or lack thereof) on mitochondrial genes in animals: tales from bivalves, electric fishes, snakes, and elephants

Nearly all eukaryotes possess a mitochondrial (mt) genome. Mt genes are popular targets for phylogenetic and population genetic analyses in animals due to their maternal inheritance, high mutation rates, and ease of amplification with 'universal' PCR primers. Variation in mt sequences is often assumed to be neutral due to the extreme functional constraints on oxidative phosphorylation (OXPHOS). However, the wealth of mt genetic data from animals is now being used to turn this assumption on its head: positive selection on mt genes has been described in diverse animal lineages. While the idea of strict mt neutrality has been systematically obliterated, cases of putative positive selection on mt genes often lack follow up experiments examining the fitness effects of mt variation. Evidence for positive selection in such studies often comes from elevated d_N/d_S ratios - the ratio of nonsynonymous to synonymous substitution rates. However, relaxed purifying selection can also produce this pattern. Here, we examined mt genomic data from several animal lineages where positive selection on mt genes has been suggested. We used tools that specifically disentangle signatures of positive selection vs. relaxed purifying selection. We find evidence in some lineages for significant, notable relaxed selection on mt genes. This challenges previous assumptions that purifying selection is unwavering in animal mt genomes. We discuss follow-up experiments underway to test these results by examining mt function in diverse lineages.

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105-2 Hawkins, OH*; Ortega-Jimenez, V; Sanford, C; Kennesaw State University, Kennesaw, GA; *ohawkin1@students.kennesaw.edu*

The contribution of the body, pectoral fins and ribbon fin to turning in a gymnotiform swimmer

Turning is an ecologically important maneuver in fishes as it is used in prey detection, predator avoidance, and the navigation of complex environments. Fishes with traditional control surfaces mostly use body bending and pectoral fins to turn. Less well known is how fishes with atypical control surfaces facilitate turning. We investigated the weakly electric Black ghost knifefish (*Apteronotus albifrons*: Gymnotidae) with an atypical control surface, the anal or ribbon fin. This fish is well known for maneuvering easily using this ribbon fin. To investigate how a fish with an atypical control surface performs turning maneuvers, we filmed *A. albifrons* using high speed videography. We captured three classes of maneuvers: steady forward swimming, small turns, and large turns. To assess which control surfaces (i.e., the body, ribbon fin, pectoral fins) contribute to turning maneuvers, we used 3D kinematic analysis. The body of turning individuals exhibits less pitch on average than steady forward swimmers. As expected, the average body bending coefficient is higher during turning compared to that of straight swimming individuals . The average pectoral fin flapping frequency, pectoral fin amplitude, ribbon-fin wave speed, and ribbon-fin frequency for turning individuals are higher than individuals swimming straight. All three control surfaces contribute to turning maneuvers. The increased frequency of pectoral fin flapping as well as the high ribbon-fin frequency and wave speed suggest they are critical drivers for turning maneuvers.

13-3 Hayashi, R*; Takagi, D; University of Hawaii at Manoa; *rintaro@hawaii.edu*

Pumping and swimming robots in a highly viscous fluid

We explore the pumping and swimming performance of rigid robotic arms in viscous silicone oil. Around a stationary body, metachronal motion pumps the fluid and generates a complex flow field. When the body is allowed to translate freely, the robot swims using metachronal motion, given the additional constraint that the arms are pointed in distinct orientations. We also show that the swimming speed increases when it is closer to confining boundaries.

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The measured displacement over time matches well with a mathematical model. Our findings reveal subtle differences in the minimal requirements for pumping and swimming with rigid arms at low Reynolds number.

90-8 Hayden, MJ*; Wicksten, MK; Texas A&M University; *haydenmaureen11@gmail.com*

Analysis of microplastic pollution on three Texas state park beaches

Within the past week have you used a straw, plastic grocery bag, plastic utensil, or a plastic water bottle? If so, then there is a likelihood that even if you properly disposed of the single-use plastic item, it might end up back in the environment. A recently published two-year survey of marine debris spanning the Gulf of Mexico (GofM) from North Padre Island National Seashore, Texas to Santa Rosa, Florida found that marine debris accumulation rates were ten times greater in Texas than similar coastlines of the north central GofM, with 69-95% of the marine debris consisting of plastics (Wessel et. al., 2019). **The goal of this study was to conduct and initial assessment of the extent of microplastic pollution on Texas state park beaches (Galveston Island, Mustang Island and Sea Rim).** Collections took place during the months of June and July during the summer and from September to November during the fall of 2019 (Permit No: 2019-R4-01). We used a modified surface sediment sampling protocol based on the NOAA Marine Debris Monitoring Program. At each beach, we laid out a 50 X 1 meter transect on the high tide line. We characterized the samples using a dissecting microscope with a camera attachment, and measured microplastics using ImageJ. Microplastics were found at all three sample sites at all collection times. Galveston Island State Park had the most microplastic pollution and amount of microplastics collected for all months sampled. We will conduct further sampling during different months to investigate trends of microplastic pollution on Texas beaches.

44-10 He, LL*; Shin, SH; Wang, Z; Yuan, I; Weschler, R; Chiou, A; Koyama, T; Nijhout, HF; Suzuki, Y; Wellesley College, Instituto Gulbenkian de Ciência, Portugal and University of Copenhagen,

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Denmark, Duke University; *lhe2@wellesley.edu*

How caterpillars assess size: The role of the TGF-beta/Activin ligand Myoglianin in triggering metamorphosis

Although the mechanisms that control growth are now well-understood, the mechanism that organisms use to assess their body size remains one of the great puzzles in biology. In insects undergoing complete metamorphosis, attainment of a threshold size specifies the final larval instar, after which growth stops and metamorphosis begins. We investigated the mechanism of threshold size assessment in the tobacco hornworm, *Manduca sexta*. The threshold size was found to vary with the amount of exposure to poor nutrient conditions whereas it was consistently lower under hypoxic conditions. Under these various conditions, the mass of the muscles plus integuments was correlated with the threshold size and *myoglianin* (*myo*) expression. Knockdown of *myo* in *Tribolium castaneum* led to larvae that stayed in the larval stage permanently even after passing the threshold size. We propose that increasing levels of Myo produced by the growing tissues allow larvae to assess their body size and trigger metamorphosis at the threshold size.

S2-4 Heath-Heckman, EAC*; Nishiguchi, M; Michigan State University, University of California, Merced; *each@msu.edu*

Exploring the genomic underpinnings of symbiosis in bobtail squid

Due to their large size (~3.5 Gb) and high repetitive content, cephalopod genomes have long been difficult to study. However, with the recent sequencing of several cephalopod genomes, including the Hawaiian bobtail squid (*Euprymna scolopes*), whole-genome studies of these molluscs are now possible. Of particular interest are the sepiolid (bobtail) squids, many of which develop photophores in which bioluminescent bacterial symbionts reside. The variable presence of the symbiosis across the group allows us to determine regions of the genome that are under selection in symbiotic lineages, potentially providing a mechanism for identifying genes instrumental in the evolution of these mutualistic associations. To this end, we have used high-throughput sequencing to generate seven bobtail squid genomes, six of which maintain symbioses with luminescent bacteria (*E. scolopes*, *E. tasmanica*, *E. hyllebergi*, *E. albatrossae*, *Sepiola affinis*, and *Rondeletiola minor*), and one of

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which does not (*Sepietta neglecta*). Using Abyss-2.0 and then Chromosomer with the published *E. scolopes* genome as a template, we generated genomes of about 76-79% completeness. For *S. neglecta*, we were able to generate a more complete genome using Illumina reads, Nanopore sequencing, and Omni-C proximity ligation. The data we have generated will enable whole-genome comparisons between these species to determine gene and regulatory content that differs between symbiotic and non-symbiotic lineages, as well as genes associated with symbiosis that are under selection. Our study is, to our knowledge, the first family-level genome comparison within the cephalopoda, and will greatly add to our knowledge of both genome dynamics within the sepiolid squid and the mechanisms in which genomes evolve to accommodate microbial symbioses.

52-3 Hedrick, BP; Louisiana State University Health Sciences Center, New Orleans, USA; *bphedrick1@gmail.com*

Inter- and intraspecific variation in Artibeus demonstrates size and shape partitioning among species

New World leaf-nosed bats (family Phyllostomidae) are one of the most diverse mammalian families and *Artibeus* is the most speciose phyllostomid genus. In spite of their species diversity, previous work on *Artibeus* crania using linear morphometrics has uncovered limited interspecific variation. This dearth of shape variation suggests a lack of niche partitioning across species, many of which are often found in sympatry. Using 2D geometric morphometric methods on a large sample of crania from eleven species from the *Artibeus* species complex (*Artibeus* and *Dermanura*), the current study demonstrates substantial cranial interspecific variation, sexual dimorphism, and intraspecific geographic variation. The majority of species were shown to have a unique size and shape, suggesting that each species is taking advantage of different niches. Both sexual size and shape dimorphism were significant in the *Artibeus* species complex. *Artibeus* species are known to have sex specific foraging strategies. The presence of cranial sexual dimorphism in the *Artibeus* species complex, combined with previous work showing that different fruit size and hardness is correlated with different cranial shapes in phyllostomids, indicates that the males and females may be utilizing different food resources, which has led to divergent cranial morphotypes. Finally, significant

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geographical shape variation was found in a large intraspecific sample of *Artibeus lituratus* crania. However, this variation was not correlated with latitude and instead may be linked to local environmental factors. Additional work on ecology and behavior in the *Artibeus* species complex underlying the morphological variation uncovered in this study will allow for a better understanding of how the group has reached its present diversity.

80-6 Heim, S*; Millard, M; Le Mouel, C; Badri-Spröwitz, A; Max Planck Institute for Intelligent Systems, Stuttgart, Germany, University of Heidelberg, Heidelberg, Germany, University of Münster, Münster, Germany; *heim.steve@gmail.com*

A little damping goes a long way

We present a new model of running which includes muscle activation and damping, and use a recently developed mathematical measure to study how the damping term affect how easily falls can be avoided. We designed a simulation experiment inspired by the famous tissue-paper experiments of Daley and Biewener, and found that the damping term in our model increases robustness of task-level stability; however, only a small amount of damping provides most of the benefit, and further increasing the damping term only has marginal benefits. These results suggest that the small amount of damping found in muscles may have a functional role, and is not simply an unavoidable source of losses to be minimized. We look forward to discussing these results with people who can follow up with more quantitative results (and anyone who is interested in general). By the time you read this, these results should have appeared in Royal Society Biology Letters. All Python code needed to reproduce our results is available at github.com/sheim/vibly.

84-8 Hellmann, JK*; Carlson, ER; Bell, AM; University of Dayton, University of Illinois, Urbana-Champaign; *jhellmann1@udayton.edu*

The interplay between sperm-mediated and care-mediated paternal effects in threespined sticklebacks

The environment experienced by one generation can influence the phenotypes of future generations (transgenerational plasticity). Because parental cues can be conveyed to offspring at multiple points in time, ranging from at fertilization to post-emergence,

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offspring can potentially receive multiple cues from their parents via different mechanisms. We have relatively little information regarding how different mechanisms operate in isolation and in tandem, but it is possible, for example, that offspring phenotypes induced by epigenetic changes to gametes may be amplified by, mitigated by, or depend upon parental care. Here, we manipulated paternal experience with predation risk prior to fertilization in threespined stickleback (*Gasterosteus aculeatus*) and then examined the potential of paternal care to mitigate and/or amplify sperm-mediated paternal effects. Specifically, we compared offspring of predator exposed fathers who were reared with or without paternal care and offspring of control, unexposed fathers who were reared with and without paternal care. We found non-additive interactions between sperm-mediated and care-mediated paternal effects on offspring stress-induced cortisol: paternal predation exposure dampened stress responses in offspring, but only when offspring received paternal care. However, regardless of the presence or absence of paternal care, offspring were less active and daughters were larger when their fathers were exposed to predation risk, suggesting that paternal care neither amplifies nor compensates for these phenotypic effects induced by sperm. These results underscore the importance of considering how multiple mechanisms affect the outcome of transgenerational plasticity.

64-1 Henschen, AE*; Dalloul, RA; Hawley, DM; Adelman, JS; The University of Memphis, Virginia Tech, University of Georgia , Virginia Tech; *henschen@memphis.edu*

Differential gene expression among house finch populations that differ in tolerance to Mycoplasma gallisepticum

Disease tolerance, whereby hosts decrease the per-pathogen fitness costs of infection, is an important component of an animal's response to pathogens. Although recent work uncovered some potential mechanisms of tolerance in animals, many others remain untested. These mechanisms are likely diverse, non-mutually exclusive, and often difficult to identify if they are not part of traditionally studied immune pathways. We used RNAseq to investigate mechanisms of tolerance in the house finch-*Mycoplasma gallisepticum* (MG) system, for which geographic differences in the emergence and spread of MG resulted in populations with distinct

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tolerance. Although down-regulated inflammatory responses are associated with MG tolerance in house finches, little is known about other potential mechanisms. To investigate mechanisms of tolerance, we examined gene expression differences between non-infected and MG-infected finches from natural populations that vary in tolerance to MG. We identified hundreds of differentially expressed genes between MG-infected birds across four populations with distinct tolerance. In support of the prediction that tolerance mechanisms are diverse, we found differential expression of genes from pathways involved in antimicrobial, heat shock, and metabolic functions, among others. These results suggest that tolerance is a multi-faceted trait that integrates molecular and physiological responses to infection, both immune and non-immune related.

44-6 Heppner, JJ*; Ouyang, JQ; University of Nevada, Reno; *jheppner@nevada.unr.edu*

Incubation behavior differences in urban and rural house wrens, Troglodytes aedon

As global land surfaces are being converted to urban areas at an alarming rate, understanding how individuals respond to urbanization is a key focus for behavioral ecology. As a critical component of avian parental care, incubating adults face a tradeoff between maintaining an optimal thermal environment for the developing embryos while meeting their own energetic demands. Urban habitats are biotically and abiotically different from their rural counterparts, i.e., in food availability, predator compositions, and the thermal environment. Therefore, urban birds may face different incubation challenges than their natural counterparts. We measured incubation behavior of rural and urban house wrens, Troglodytes aedon, with temperature loggers throughout the 12-day period. We found that urban females had more incubation bouts of shorter duration and spent less total time incubating per day than rural females. Results provide evidence of behavioral shifts of wrens in cities, which have implications for the evolution of parental care. Our findings contribute to our understanding of the behavioral traits needed for city life and possible mechanisms driving urban adaptations.

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62-7 Herath, JCB*; Meegaskumbura, M; Guangxi University, China; *jayampathi_herath@yahoo.com*

Investigating the disease ecology of Ranaviruses (Family Iridoviridae) in ectothermic vertebrates of southern China

Ranavirus infection is an emerging group of dsDNA viruses, which cause systemic infection of ectothermic vertebrates. The rising interest in Ranaviruses is due to sudden increases in range across the world and evidence of host-population declines. Ranavirus has been detected in China, associated with population declines of several species - species of conservation importance, the Giant Chinese salamander (*Andrias davidianus* , Critically Endangered), native species such as *Rana dybowskii* and *Rana amurensis* and several species of economic concern such as largemouth bass (*Micropterus salmoides*) and tiger frog (*Rana tigrina rugulosa*). Strategic monitoring in southern China is required to understand disease prevalence and determine species at risk. Sampling design focus on disturbed and undisturbed habitats across a latitudinal gradient together with opportunistic sampling of culture facilities and pet markets, known hotspots for the disease. Swabs taken from oral cavity, cloaca, or skin lesions and DNA were extracted from QAIGEN UCP Pathogen Mini kit. A set of primers and TaqMan (developed and partially validated to detect a panel of 33 different ranaviral isolates) were used. Our initial results indicate that some of the Chinese tiger frog (*Hoplobatrachus cf. rugulosus*) from culture facility are infected with Ranavirus. This could be the first case of Ranavirus recorded in this region, which indicates that some of the cultured amphibian species could be responsible for spread of the disease. Understanding of disease ecology, anthropogenic influence, reservoir species is important in managing the disease to conserve species at risk.

54-4 Herbert, AM*; Higham, TE; University of California Riverside; *aherb012@ucr.edu*

Feeding at the air-water interface: how prey position influences suction and ram in largemouth bass

Altering prey capture behavior with changing prey properties is advantageous for many organisms. For fish that live in variable

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environments with many types of prey, the ability to catch prey throughout the water column and at/on the surface is likely a necessity to survive and thrive. For fish that rely on suction feeding, the air-water interface should pose a challenge given the discontinuity in fluid density between air and water. Largemouth bass (*Micropterus salmoides*) are known to alter aspects of feeding strikes in response to prey type, prey motion, light levels, and sensory deprivation. In this study, we used 3D high-speed video to quantify the kinematics (ram speed, strike angle, maximum gape, time to peak gape, suction performance) of largemouth bass feeding on pellets at the surface and in the water column. Additionally, we quantified both horizontal and vertical attacks on pellets at the surface. Time to peak gape varied with prey position and the mouth opened faster in surface strikes. The timing of braking also changed with prey position - for strikes on pellets at the surface, braking began at the start of suction or prey capture, whereas braking began after suction or prey capture for mid-water strikes, as shown in previous studies. Therefore, it appears that largemouth bass adopt more of a suction feeding strategy when capturing prey at the air-water interface.

BSP-11-4 Herbst, EC*; Eberhard, E; Manafzadeh, AR; Richards, C; Hutchinson, JR; University of Zurich, Switzerland, EPFL, Lausanne, Switzerland, Brown University, Providence, RI, The Royal Veterinary College, London, UK; *eva.herbst@pim.uzh.ch*

New methods support the possibility of a salamander-like walk in the Permian tetrapod Eryops

Joint range of motion (ROM) studies help paleontologists constrain locomotor reconstructions. However, no method currently exists to reproducibly integrate ROM data from several limb joints to test whole limb configurations. Here we present a new method for doing so and use it to test whether *Eryops megacephalus* could adopt a salamander-like gait. We first measured the full ROM of the hip and knee joints of salamander cadavers with only the joint capsule and ligaments intact. We then used scientific rotoscoping to analyze the in vivo ROM used by salamanders during walking. Based on these data, we suggest that in vivo studies offer data for comparisons to fossil taxa that are not available from ex vivo manipulation alone. Therefore, we focused on four limb configurations from the

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salamander terrestrial stride cycle: toe off, mid swing, toe on, and mid stance. Then, we built a "digital marionette" of *Eryops* and measured the osteological ROM of its hip and knee. Our new method creates a visual representation of all possible joint poses at each joint of the marionette. We then placed the marionette in each of the four key salamander limb configurations. Our method allowed us to determine that the poses required at both joints to replicate the salamander limb configurations fall within the osteological ROM of *Eryops*. Based on these results, we conclude that *Eryops* might have been capable of a salamander-like lateral sequence walking gait. Future studies that incorporate other lines of evidence, such as soft tissue reconstructions and kinetic constraints, will help to further test this hypothesis.

22-8 Herbst, HD*; Scheurle, D; Clark, A; Porter, ME; Florida Atlantic University, Department of Biological Sciences, Boca Raton, FL, USA; *hherbst2015@fau.edu*

Variable roughness of shark skin inspired surface impacts bacterial migration rates

Shark skin is covered with denticles that create micropatterns. Many shark skin inspired surfaces have non-overlapping micropatterns that have been shown to be antifouling. However, the overlapping and irregularly shaped denticles of shark skin, which control adhesion of bacteria, have not been replicated on bioinspired surfaces. In our experiments, we developed shark skin inspired surfaces with ridge-covered overlapping protrusions resulting in variable roughness. We hypothesized that migration and adhesion of *Staphylococcus aureus* and *Staphylococcus epidermis* would be reduced on these rough surfaces compared to a flat commercial bandage and flat control due to surface interactions such as Van der Waals forces, steric, and electrostatic interactions, which are known to influence bacterial settlement. Skin samples from bonnethead sharks (*Sphyrna tiburo*) were micro-CT scanned and had roughness between 11 and 53 denticles / mm2. We developed surfaces resulting in five different roughness factors between 1.972 and 16.026 μm using PDMSe elastomer and assessed for growth of *S. aureus* and *S. epidermis*. Surfaces with similar morphology and roughness to bonnethead shark skin were significantly more effective at blocking bacterial adhesion and

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migration compared to a commercial bandage and flat PDMSe control. These surfaces have potential to reduce healthcare associated infections in hospital settings.

26-6 Herhold, HW*; Davis, SR; Grimaldi, DA; American Museum of Natural History; *hherhold@amnh.org*

Insectahemoglobins: Transcriptomes reveal expression of hemoglobins throughout Insecta

One of the defining characters of insects is their mechanism of respiration: tracheae, an elaborate system of chitinized ectodermal tubules, delivering oxygen directly to tissues. While hemoglobins have been characterized in a few insects, the supposed adequacy of tracheae has led to the long-held assumption that insects do not require respiratory proteins. A comprehensive analysis of 845 Hexapod transcriptomes revealed the expression of hemoglobins in 32 orders of hexapods, including all 29 recognized orders of insects. Discovery of 1333 putative hemoglobins was achieved with target-gene BLAST searches of the NCBI TSA database, followed by verification via identification of functional residues, secondary- and tertiary-structure predictions, and localization predictions. While the majority of these hemoglobins are intracellular, extracellular hemoglobins were recovered in 38 species. Gene trees were constructed using multiple-sequence alignments and phylogenetic analyses. These results indicate duplication events within Insecta and a monophyletic grouping of hemoglobins outside other globin clades, for which we propose the term insectahemoglobins. Insectahemoglobins appear structurally convergent with and are phylogenetically adjacent to the clade of chordate myoglobins, cytoglobins, and hemoglobins. The co-option and derivation of insectahemoglobins from early neuroglobins may explain the widespread nature of hemoglobins in various kingdoms and phyla. It is hoped that these results can guide future work, including genome comparisons to transcriptome results, cell and tissue localization, experimental investigations of gene expression, and gas binding properties, to further illuminate the complex respiratory adaptations in insects.

S1-4 Hermans, C*; Koblitz, JC; Litovska, I; Visser, ME; Spoelstra,

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K; Netherlands Institute of Ecology (NIOO-KNAW), Wageningen, Max Planck Institute of Animal Behavior, Konstanz, Germany ; *c.hermans@nioo.knaw.nl*

Effects of artificial light at night on the spatiotemporal pattern of bats and insects

Urbanization is a major threat for biodiversity due to various sources of pollution, including artificial light at night. The growth of lit outdoor areas is likely to affect nocturnal ecological communities. Bats are particularly vulnerable to light pollution since they are almost exclusively nocturnal and strongly react to light. Previous studies showed that bat activity varies with light spectrum, with less activity disturbance by red light. In addition, the use of red light decreases indirect impact on bats by a reduced accumulation of prey insects. However, our knowledge on how bats alter their spatiotemporal behavior in response to different artificial light spectra, and how this depends on light intensity, is limited. We investigated these effects on bats foraging in forest edge habitat at replicated, long-term experimentally illuminated transects. We assessed insect availability throughout the night by taking pictures with infrared cameras around light posts emitting white-, red- or no light. We recorded bat foraging activity through the night and used microphone arrays to reconstruct flight patterns of bats and localize feeding attempts by associating each call to a 3D-position. We expect bat activity to follow prey insect availability, which varies throughout the night by light treatment. Light may cause insects to be present all night, and subsequently bats will continue to forage throughout the night. We further explore the spatial distribution of feeding attempts around the light in bats with different foraging strategies.

S4-11 Hernandez, T; Donnelly-Hermosillo, D*; Person, E; Hansen, A; California State University Fresno; *ddonnelly@csufresno.edu*

Using zoos as a context to teach authentic research: reflections from first and second experience students taking introductory chemistry

Zoos are predominantly considered as environments to teach concepts of conservation and biology, and such considerations are reflected in undergraduate biology curricula. However, zoo-based exhibits are

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underpinned by a myriad of chemistry concepts yet such connections are largely absent from undergraduate chemistry curricula. This study investigates a new zoo-context guided-inquiry laboratory structure within an Introductory Chemistry course for students taking the course for the first time (first-experience), and students taking the course a second time with the new structure (second-experience), having failed the course in a conventional format a previous semester. The conventional laboratory format was designed to reinforce lecture content with cookbook-style laboratories while the zoo-based laboratory structure was focused on supporting student-designed investigations tied to zoo exhibits. Using interviews (n = 10 female students), we sought to understand students' experiences and how such experiences could inform future iterations of the zoo-based structure. Through inductive thematic analysis, we found three themes describing student experiences in both laboratory environments - sense of community, relevancy of the work, and ownership of the experiments. This work describes the nuances across student perspectives of laboratory approaches and the implications of these findings for iterations to laboratory structures.

BSP-5-6 Hernandez, J*; Belden, LK; Moore, IT; Virginia Tech, Blacksburg, VA; *jess228@vt.edu*

Exploring the cloacal microbiome and fitness correlates in female tree swallows

Animals host microbial communities ('microbiomes') that inhabit most every niche of their body and these microbiomes can influence host development, physiology, and behavior. Previous work has predominantly focused on the gut, oral, and skin microbiomes, leaving open the question of how other microbiomes, such as the reproductive microbiome, are related to host phenotype and, most importantly, host fitness. Here, we assessed how multiple aspects of the cloacal microbiome are related to various fitness-related traits in free-living female tree swallows (*Tachycineta bicolor*), a commonly studied cavity-nesting bird. Cloacal swabs were collected from female tree swallows during incubation from 2017 to 2019, and 16S rRNA gene amplicon sequencing was used to characterize cloacal microbiomes. We considered the following fitness-related traits: lay date, number of eggs laid, average brood mass, number of young

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fledged, hematocrit, and H:L ratios. Given the growing trend of measuring various microbiomes in a diversity of contexts, our results may underscore the importance of determining rather than assuming the functional significance of microbiomes in free-living animals.

12-3 Herrera-Amaya, A*; Byron, ML; Penn State University; *auh1002@psu.edu*

Measuring metachronal maneuvering at the milliscale: an analysis of ctenophore swimming kinematics

Ctenophores (comb jellies) are the largest animals in the world who locomote primarily using cilia. Despite the relative simplicity of this propulsive system, they possess unusually impressive maneuvering capabilities. Ctenophores group their cilia in coordinated platelike bundles called ctenes, which are arranged in eight rows circumscribing the body. Ctenes in each row are metachronally coordinated, but each row's frequency and beat direction can be independently controlled. This coordination allows the animals to swim forward and backward at nearly the same speed, and to turn rapidly with small turning radii. This surprising agility appears across a wide range of animal sizes, and bridges the gap between the viscous-dominated (low Reynolds number) and inertial-dominated (high Reynolds number) fluid dynamic regimes. To quantify the locomotion of freely swimming ctenophores, we used deep learning-based kinematic tracking to reconstruct animal trajectories, extracting the position and orientation of the animal during complex three-dimensional maneuvers. These measurements allow us to calculate performance parameters such as (e.g.) minimum length- specific turning radii, maximum angular and translational velocities and accelerations, and backward to forward swimming speed ratio (B:F). Our results show that at similar angular velocities ctenophores can achieve a length- specific turning radius two times smaller than other centimeter scale zooplankton. Furthermore, they also exhibit the unusual case of a B:F close to one. By quantifying the swimming behavior of ctenophores, we provide a first step toward the potential development of bio-inspired devices, sensors, and vehicles that may be able to leverage similar systems in the intermediate Reynolds number regime.

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S10-7 Herrera-Amaya, A; Byron, ML*; Pennsylvania State University; *mzb5025@psu.edu*

Spatiotemporal asymmetry in ctenophores: metachronal locomotion at intermediate Reynolds number

The cilium is a canonical low-Reynolds number propulsor, occurring primarily at the scale of microns to tens of microns (with Reynolds numbers of less than 10^{-2}). Because of the time-reversible nature of viscous-dominated flows, the power stroke of a cilium must be spatially asymmetric in order to be effective: a completely symmetric movement would produce no net fluid displacement, even if the power stroke were much faster than the recovery stroke. However, ctenophores (comb jellies) use cilia at much larger scales—their unique millimeter-scale ciliary bundles (ctenes) produce flows at intermediate Reynolds numbers, on the order of 10-200. In this regime, inertia and viscosity both play important roles in generating fluid motion; spatial asymmetry is not as crucial, and temporal asymmetry (difference in duration between the power and recovery strokes) may begin to play a role. We measure this spatiotemporal asymmetry in two species of ctenophores (*B. vitrea* and *B. infundibulum*) across a range of body sizes and Reynolds numbers, from 7mm to 40mm in length. We use Particle Shadow Velocimetry (PSV) to observe the fluid flows generated by the ctene rows of animals across this same range, and compare flow characteristics between small, medium, and large animals. Finally, we use a simple mathematical model to explore the role of spatiotemporal asymmetry in the efficacy of metachronally coordinated appendages across scales. Our results inform our understanding of ctenophores' interactions with their environment across ontogeny, and provide insight into drag-based swimming in the under-studied intermediate Reynolds number regime.

49-8 Heuermann, TM*; Kozlovsky, DY; Curry, RL; Villanova University; *theuerma@villanova.edu*

Understanding boldness variation among hybridizing black-capped and Carolina chickadees

As rapid climate change introduces novel environmental conditions, understanding how species vary in their response to change is

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urgent. Animal personality, behavior consistent within and variable among individuals, influences how populations adapt and respond to new challenges. Our research program focuses on interactions between Black-capped (*Poecile atricapillus*) and Carolina (*P. carolinensis*) chickadees across a northward-moving hybrid zone in southeastern Pennsylvania. We investigated nest defense behaviors as a proxy for boldness, a component of personality associated with an individual's willingness to interact with a perceived threat. We simulated predation threats at nests in pure and mixed populations with a motorized decoy. Video analysis yielded measures of pair responses for three categories of boldness behaviors: approach latency, vocalization, and proximity to the decoy. All behaviors were moderately repeatable, as is typical for behavioral phenotypes. We modeled each behavior using linear and generalized-linear mixed methods. Preliminary analyses suggest the odds of observing a slow approach from Carolina or hybrid pairs were respectively over triple and nearly double the odds of observing a slow approach from Black-capped pairs. Carolina pairs expressed more alarm (mean 3.7 *dee* notes) in their calls than Black-capped pairs. Black-capped pairs remained close to the decoy more often than Carolina and hybrid pairs. Based on current models, we conclude that Black-capped chickadee pairs are bolder than Carolinas, with hybrids generally intermediate or more Carolina-like. These results indicate the importance of considering personality variation as ranges shift and foster new or greater contact between potential mates and/or competitors.

79-1 Heveran, PH*; Goodrich, LJ; Leese, JM; DeSales University, Hawk Mountain Sanctuary; *ph8986@desales.edu*

Age-class differences in wintering distributions among broad-winged hawks

Recent studies on endangered species, including the Kirtland's warbler (*Setophaga kirtlandii*) and the piping plover (*Charadrius melodus*), have shown the importance of knowing a species' wintering range for effective conservation efforts. These species were protected on their breeding grounds, but when their wintering range was described, new threats were identified. Despite the broad-winged hawk (*Buteo platypterus*) being an easily observed North American raptor during migration, much is still unknown about its

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non-breeding distribution. This study's goal was to uncover patterns in adult and immature broad-winged hawk distribution in winter. Public eBird data from 2000-2017 between December and February were analyzed. We found no significant difference between mean wintering latitudes of adults and immatures south of the United States. This was true at most regional levels in the US as well. A few patterns did not concern mean wintering latitude but did show differences in distribution between age groups. All regions had more sightings of immature than adult individuals. The Florida ratio was unexpected, given previous indications of a mostly immature population. Sightings of adults were concentrated in higher-elevation forests in areas such as Costa Rica and Colombia. Immature sightings were more widespread in forests and lowland habitats. These findings have direct implications for more effective conservation measures in protecting the species. If a significant number of immature birds are wintering farther north than previously thought, conservation efforts may need to expand from the traditional core winter range. Although broad-winged hawks are still common, threats in these different habitats could contribute to a population decline if not identified.

106-4 Hill, AH*; Hall, C; Camilli, S; Dwaah, H; Kornegay, B; Lacy, CA; Hill, M; Bates College, University of Virginia, Princeton University, Tufts University, University of Richmond; *ahill5@bates.edu*

The freshwater sponge, Ephydatia muelleri, and its chlorophyte symbiont: a model to understand intracellular symbiosis

The recent publication of a chromosomal-level assembly of the genome of the freshwater sponge, *Ephydatia muelleri*, increases the utility of this species as a non-bilaterian model. In addition to its role in helping us understand early animal evolution and freshwater adaptations, *E. muelleri* provides an opportunity to study the evolutionary origins and ecological persistence of endosymbiosis. In many freshwater habitats, green algae form intracellular symbioses with a variety of heterotrophic host taxa including several species of freshwater sponge like *E. muelleri*. We examined the association between *E. muelleri* and its chlorophyte partner to identify features of host cellular and genetic responses to the presence of intracellular algal partners. Chlorella-like

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green algal symbionts were isolated from field-collected adult *E. muelleri* tissue harboring algae. The sponge-derived algae were successfully cultured and subsequently used to reinfect aposymbiotic *E. muelleri* tissue. We used confocal microscopy to follow the fate of the sponge-derived algae after inoculating algae-free *E. muelleri* to show temporal patterns of symbiont location within host tissue. We also infected aposymbiotic *E. muelleri* with sponge-derived algae, and performed RNASeq to study differential expression patterns in the host relative to symbiotic states. Our work demonstrates that freshwater sponges offer many tractable qualities to study features of intracellular occupancy and thus meet criteria desired for a model system and opens avenues to uncover possible conserved evolutionary pathways that may lead to stable mutualistic endosymbioses.

62-9 Hill, EH*; Butler, MA; University of Hawaii; *hille7@hawaii.edu*
Where Do They Come From, Where Do They Go? A Phylodynamic Analysis of SARS-CoV-2 in Urban Centers
Currently, there have been over 20 million confirmed cases of COVID-19 worldwide; 6.2 million of which have occurred in the United States of America. Within the US, the hardest hit locations were urban centers. Although the population dynamics of these large scale SARS-CoV-2 outbreaks in urban centers are unclear, the high population density of these urban centers create an ideal environment for extremely rapid community transmission to occur. On the other hand, urban centers may also act as international travel hubs presenting opportunities for the influx of multiple, and potentially more transmissible, lineages of SARS-CoV-2 into the population. We will investigate if the SARS-CoV-2 outbreaks in urban centers and in particular whether they occur as a result of rapid community spread of a single lineage or as a result of the accumulation of multiple smaller outbreaks that are associated with the introduction of multiple distinct lineages. Using the SARS-CoV-2 genomes available through NCBI and GISAID, we will conduct a phylodynamic analysis using a time calibrated Bayesian phylogeny under a Bayesian Skyline prior to compare the timing and number of introduction events, the number of distinct lineages present, and the effective reproduction size and effective population size of SARS-CoV-2 between urban centers. Elucidating the dynamics of SARS-

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CoV-2 transmission will provide valuable insights about the virus' spread in densely populated travel hubs.

59-8 Himes, AR*; Rivest, EB; McDowell, JR; Reece, KS; Snyder, RA; Virginia Institute of Marine Science, William & Mary; *arhimes@vims.edu*

Assessing environmental tolerance of Mercenaria mercenaria along the east coast of the United States

With increasing water temperatures and altered precipitation patterns in coastal systems due to climate change, there is an increasing need to understand the environmental tolerances of coastal species and how they will respond to future habitat conditions. It is also necessary to understand the variation in environmental tolerance across a species' range in order to predict the broader impacts of climate change. In this study, the physiological effects of elevated temperature and lower salinity were assessed for juvenile hard clams, *M. mercenaria*, sampled from six populations ranging from Massachusetts to North Carolina. For each population, metabolic rate was measured using respirometry across four elevated temperature (27.5° C, 30° C, 32.5° C, and 35° C) and three lower salinity (20, 15 and 10) conditions. The treatment levels selected are representative of current and future conditions projected for Chesapeake Bay, VA. Mortality was also assessed at an environmentally relevant, elevated temperature (36° C). Preliminary analysis showed differences in temperature-related mortality rate among the six populations. The variations among these populations illustrate that the effects of climate change on hard clams will not be uniform and that some populations are more susceptible to environmental change than others. These results can help predict the future success of this species and its commercially important stocks, as well as provide insight for the aquaculture industry about the potential for breeding more resilient broodstock lines.

8-3 Hirzel, GE*; Westerman, EL; University of Arkansas, Fayetteville; *gehirzel@uark.edu*

Surveying seasonal changes in behavior and wing coloration in a polyphenic butterfly

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Many animals adopt specific morphs in response to changing environmental conditions that are associated with seasons. Morphological differences are often accompanied by changes to behavior as well. In butterflies, studies on associations between behavior and morphology are often conducted in the lab. To test how seasonal conditions affect both morphology and behavior in natural settings, we examined wild populations of *Junonia coenia*, a butterfly with well documented seasonal wing patterns. We collected data in 2018, 2019, and 2020 from May to November in three prairie sites in Northwest Arkansas. Every two weeks we visited sites to conduct focal watches, point counts, and transect surveys. On survey off-weeks we collected butterflies to record wing coloration. We found that there was an effect of season on behaviors, including flying, nectaring, resting and basking. There was also an effect of season on wing coloration. Collected butterflies began getting darker and were more likely to be classified as a fall morph starting in September. This change in coloration correlates to a decrease in weekly temperature, which corroborates past work in this species. Only a change in basking behavior correlated with this change in wing color. As wings of collected butterflies became darker, basking behavior increased. These results lay the foundation for understanding a holistic seasonal phenotype in *J. coenia*, a species in which most research efforts have been directed toward morphological studies. As typical seasonal conditions shift due to climate changes and land use, understanding how ambient conditions affect seasonal behaviors will be important for predicting changes in behavior of wild populations of butterflies and other pollinators.

39-6 Hodge, JR*; Friedman, ST; Wainwright, PC; Price, SA; Clemson University, Yale University, University of California, Davis; *jhodge6@clemson.edu*

Linking body form to ecological function in coral reef fishes

Organismal traits evolve in ecological arenas and can therefore provide important links between ecological processes and macroevolutionary patterns. However, the usefulness of trait-based approaches hinges on the relationship between trait states and ecological function. Fishes are the most diverse vertebrate assemblage on earth and their dominance in marine food webs impacts

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ecosystem processes such as nutrient cycling and habitat maintenance. The dizzying diversity of fish morphology is thought to primarily reflect how fish function (i.e. how they feed and locomote), rather than the resources they consume. While there are many examples of form reflecting performance, the complex nature of fish morphology means there are also many counter examples of multiple structural configurations performing the same function, as well as functionally diverse morphologies. The relationship between trait diversity and trophic niche is well established within certain taxonomic lineages, but we lack consensus about the structure and generality of these form-function relationships. Here we explore the structure of morphological diversity within the global coral reef fish community and its connection to trophic functions. Using a phylogenetic framework, we assess whether traits that describe body shape can adequately quantify dietary and foraging niche categories. Then, we investigate how differences in species richness between major ocean basins relate to the occupation of functional trait space. Preliminary results suggest that, relative to the Atlantic, higher species richness in the Indo-Pacific is associated with denser morphospace occupation, implying increased specialization or niche packing. Our findings will enable further exploration of the reciprocal processes responsible for the assembly of biodiversity and provide a more nuanced understanding of community composition.

53-1 Hodinka, BL*; Williams, TD; Simon Fraser University, Burnaby, British Columbia; *bhodinka@sfu.ca*

How do birds assess their own body mass? Testing how rapidly birds can respond to experimentally increased mass

Birds can display large spatio-temporal daily and seasonal variation in body mass. For example, birds generally have higher mass in winter when food supply is unpredictable or when there is less time for feeding. In contrast, opportunities for self-feeding should be reduced during breeding, when food needs to be provided to chicks, yet many adult birds decrease body mass. This could reflect a cost of parental care or a strategy to decrease costs of hard work through lowering wing loading. While "adaptive" modulation of body mass is well documented, two fundamental questions remain: a) how do birds assess their own body mass, and

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b) what mechanisms may birds use to rapidly adjust body mass? Here we describe a proof-of-concept study using captive zebra finches (*Taeniopygia guttata*) to test how rapidly birds can strategically adjust mass in response to an externally mounted weight and if behavior is a key correlate of this response. Individuals (n = 40) were separated based on sex and divided between four cages (n = 10 per cage). After two weeks of habituation (day 0) individuals were weighed and assigned to the control group or assigned weighted backpacks based on initial mass (e.g., 13.0 g bird = 1.30 g weight) to ensure backpacks were all approximately 10% body mass. Every other day (day 0-22), individuals were weighed at 09:30, returned to their home cage, and filmed for 1 h beginning at 12:00. Weighted backpacks were removed on day 14 but continued to be weighed and filmed every other day until day 22. Data suggest zebra finches rapidly lost mass (between days 0-2), but only partially compensated for the additional weight, before re-establishing constant, lower mass. They then re-established initial mass upon removal of weighted backpacks.

S6-1 Hoke, KL*; Hensley, NM; Kanwal, JK; Wasserman, SM; Morehouse, NI; Colorado State University, Cornell University, California Institute of Technology, Wellesley College, University of Cincinnati; *kim.hoke@colostate.edu*

Introduction to the symposium: Spatiotemporal dynamics of animal communication

An animal's position in space and time determines its ability to collect information about the world around it. These spatiotemporal concerns are of particular importance to animals engaged in communication with each other: the relative spatial positioning of sender and receiver over time can help to optimize information exchange or hamper it because sensory systems and the signals that stimulate them are often highly directional. To understand how spatiotemporal dynamics are coordinated by participants in a communication system and how these dynamics shape evolution, this symposium addresses biomechanical, neurophysiological, and ecological constraints on display performance, navigation, and orientation towards receivers. We further consider receiver encoding of complex signals and how these factors impact success in communication and the associated decision making, from

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neurobiological, cognitive, and philosophical perspectives. We further consider receiver encoding of complex signals from neurobiological, cognitive, and philosophical perspectives. We leverage machine learning and social network tools to characterize spatiotemporal dynamics of interactions. Our symposium integrates cross-disciplinary perspectives to open exciting new avenues of inquiry that should pay dividends across these fields and beyond.

42-5 Holden, KG*; Sparkman, AM; Miller, DA; Bronikowski, AM; Iowa State University, Westmont College, Pennsylvania State University; *pettinkg@iastate.edu*

A decade of field-physiology reveals life-history specific profiles in garter snakes (Thamnophis elegans)

Life-history theory posits resource-based trade-offs among traits such as growth, reproduction, and survival. These trade-offs are hypothesized to constrain the covariation of life-history traits along a slow-to-fast continuum. In this framework, populations of the same species that experience different habitat conditions are expected to diverge in life histories, and concomitantly, in metabolic and energetic traits that support life-history traits. Physiological hypotheses that result from this pace-of-life (POL) theory include predictions about immune function and metabolism, i.e., more reliance on and investment in acquired immune function and slower metabolic rates in slow POL individuals. Less clear is how stress physiology should associate with POL, in part because of the vast number of physiological markers that could be characterized as mediators of a stress response. Here we use long-studied natural populations of the western terrestrial garter snake (*Thamnophis elegans*) representing two life-history strategies from the vicinity of Eagle Lake, CA. From 2010-2019, we tested hypotheses that baseline and reactivity of plasma corticosterone, glucose, and leukocytes vary across years and with directionalities consistent with life-history theory. We found significant POL-specific annual variation in both baseline and stress-induced physiological traits generally in agreement with theoretical predictions.

S1-7 Hölker, F*; Kühne, JL; Jechow, A; van Grunsven, RHA; Leibniz-

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Institute of Freshwater Ecology and Inland Fisheries (IGB), Berlin, Germany, IGB, Berlin, Germany, Dutch Butterfly Conservation, Wageningen, The Netherlands; *hoelker@igb-berlin.de*

Impact of different colors of artificial light at night on phototaxis in aquatic insects

The use of artificial light at night (ALAN) is increasing exponentially worldwide and there is growing evidence that ALAN contributes to the decline of insect populations. Especially light sources with short wavelength emissions have been shown to attract the highest numbers of flying insects. Furthermore, aquatic flying insects are reported to be more vulnerable to ALAN than terrestrial insects. This is concerning because freshwaters are likely affected by ALAN that originates from human activity centers, which are typically close to freshwater systems. However, the effects on aquatic insects, that spend their larval phase or their whole life cycle in freshwaters, are entirely understudied. Here, we investigated phototaxis of aquatic insects to ALAN at different wavelengths and intensities. We used floating light traps and compared 4 near-monochromatic colors at 2 different light intensities in an ALAN-naïve ditch system. Similar to flying insects, we found a strong positive phototaxis of aquatic insects to ALAN. However, there is no preference for short-waved light. Overall, wavelengths in the center of the visible range (green, yellow) cause the strongest attraction. This is likely an adaption to how light propagates in aquatic systems, where the water itself and optical constituents act as a color filter. Also, insects living in freshwater bodies often live in green-dominated environments and might therefore be especially sensitive to green light. In conclusion, the different spectral sensitivities of both aquatic and terrestrial organisms have thus to be taken into account when planning lighting near fresh water systems.

98-8 Holliday, CM*; Wilken, AT; Sullivan, SP; Sellers, KC; Cost, IN; Middleton, KM; University of Missouri, University of Chicago, Albright College; *hollidayca@missouri.edu*

Myology of the Reptilia

Sauropsid vertebrates (lepidosaurs, turtles, crocodilians and birds) have evolved a diversity of head shapes and feeding behaviors during their history. A key to understanding this great

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radiation of reptiles is the physiology of the jaw musculature that powers the feeding apparatus. However, we still know little about jaw muscle mechanics within lineages of reptiles or how this complicated musculoskeletal system has evolved to employ a variety of behaviors. New imaging and computational methods are now enabling an extraordinary view into the 3D anatomy and biomechanics of reptiles and other vertebrates. Here we illustrate several approaches to analyzing jaw muscle morphology and architecture using contrast imaging, 3D fiber tracking, biomechanical analysis, and data visualization methods that offer enormous potential for exploring the anatomy, function and evolution of jaw muscles. We first illustrate basic workflow of 3D jaw muscle imaging, visualization, morphometrics, and interpretation using crocodilian jaw muscle anatomy. Second, we show how homologous jaw muscle bellies evolve among lineages of different reptiles and birds to elicit different functional demands. Third, we show how the 3D architecture of small, deep protractor muscles correlate with different types of cranial kinesis among a sample of lizards and birds. Many of these muscles leave traceable osteological correlates in the fossil record of reptiles and other vertebrates that can better guide inferences of muscle functional anatomy and joint loading environments. These new imaging and analytical approaches offer incredible potential for the quantification of soft tissue morphology and have remarkable applications to comparative biomechanics, ecomorphology, and paleobiology.

26-9 Hood, WR; Auburn University; *wrhood@auburn.edu*
Life history, condition dependency, and mitochondrial performance
In response, ecologists and evolutionary biologists often record and include body mass as a co-variant in their studies and assume that animals with a higher body mass are in better condition, despite the knowledge that obesity can have numerous negative impacts on fitness. In 2011, Hill defined condition as the relative capacity to maintain optimal functionality of vital systems (Ecology Letters 14:625) and further suggested that cellular respiration efficiency would be among the best indicators of condition (Integrative and Comparative Biology, 2014,54:645). With this presentation, I will describe the relationship between body mass and mitochondrial performance in several species and contexts.

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I will highlight work on ICR mice, showing that the interaction between mitochondrial performance and body mass is highly dependent on reproductive experience. My lab group observed that non-reproductive mice displayed a negative relationship between body mass and mitochondrial respiratory capacity; in contrast, females that experienced four reproductive events displayed a positive relationship between body mass and mitochondrial respiratory capacity. I will discuss the significance of these findings to our understanding of the interactions between body mass, condition, and the fitness of animals.

11-2 Hood, KE*; Hurley, LM; Indiana University; *hoodk@indiana.edu*
Effects of systemically and locally increased serotonin on male response to female rejection calls
Neuromodulatory systems, like the serotonergic system, innervate both sensory brain regions and regions involved in social behavior, making them likely candidates for representing social information in sensory systems. In an auditory midbrain nucleus (inferior colliculus; IC) of male house mice (Mus musculus), levels of serotonin are sensitive to both auditory and social stimuli. Serotonin in the IC of males increases when they are with a female partner, but the degree of that increase negatively correlates with the rejection behaviors, including the number of broadband vocalizations (BBVs) that females exhibit. Therefore, we hypothesize that serotonin in the IC of males encodes female receptivity during sexual interactions. To directly test the relationship between serotonin in the IC and perception of rejection BBVs, we infused a control (aCSF) or serotonin-releasing (fenfluramine) solution into the IC of males before BBV playback. Both control males and males with increased IC serotonin reduced ultrasonic vocalization (USV) production to BBV playback. However, fenfluramine-injected males produced fewer USV syllable types and had a more pronounced recovery after the end of BBV playback when compared to control males. Fenfluramine was also injected systemically into males prior to BBV playback to assess the role of a more widespread serotonergic increase. Fenfluramine depressed baseline vocalizations to the extent that further suppression by BBV playback could not be detected. Therefore, local increased IC serotonin does not change immediate USV response to female

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rejection vocalizations but may impact USV syllable repertoire and recovery, and systemic and local fenfluramine- induced increases in serotonin have markedly different effects.

S10-6 Hoover, AP*; Katija, K; Daniels, J; Osborn, K; The University of Akron, Monterey Bay Aquarium Research Institute, Smithsonian Institute; *ahoover1@uakron.edu*

A fluid-structure model for the parapodia of tomopterids

Inhabiting the midwater regions of the oceans, tomopterids are a family of pelagic, gelatinous polychaetes whose motion is highly adapted to navigating the water column. Their locomotion is governed by the motion of their parapodia, a soft, gelatinous paddle-like appendage attached to the base of the body. Lined up along the body in the horizontal plane, the metachronal paddling of the parapodia drive the swimming behavior of tomopterids. The motion of the individual parapodium is a result of the interaction between the swimming musculature and the elastic properties of the parapodia. In this study, we develop a model for the individual parapodia and allow its motion to emerge as a result the muscle actuation on the flexible parapodia. The fully-coupled fluid structure interaction problem is solved using an adaptive and parallelized version of the immersed boundary method (IBAMR). We will then compare the results of the simulations with the motion of the parapodia.

20-5 Hope, SF*; Hopkins, WA; Angelier, F; Centre d'Etudes Biologiques de Chizé, France, Virginia Tech; *shope@vt.edu*

Parenting in the city: Does urbanization influence avian incubation behavior?

As urbanization continues to increase, it is crucial to understand how animal populations respond. Urban areas are associated with changes in microclimate, light, noise, and human activity, which can affect the physiology, behavior, and fitness of animals. In particular, urbanization may affect how parents allocate their time and energy between parental care and self-maintenance. In birds, one of the most important aspects of parental care is incubation, where parents must maintain egg temperatures for successful offspring development. However, incubation is energetically costly

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for parents, and urbanization may further affect this cost. Determining how urban-induced behavioral changes may affect incubation behavior and egg temperature is crucial for understanding how urban animals cope with the parental care/self-maintenance tradeoff, and the consequences for their offspring. We measured incubation behavior and temperature in urban and forest populations of great tits (*Parus major*) using temperature loggers. We predicted that urban birds would spend less time incubating, due to urban constraints such as noise, human disturbance, and reduced food quality. In contrast to our prediction, we found that urban parents spent more time incubating than forest parents. However, despite the increased time spent incubating, urban eggs experienced greater daily variance in incubation temperature than forest eggs. Further, urban birds ended their last daily off-bouts at a later hour than forest birds. Our results suggest that urbanization can influence both avian parental behavior and the thermal environment of their offspring during development. More work is needed to determine whether these changes translate into fitness consequences.

1-2 Hopkins, GR*; Elgar, MA; Gaston, KJ; Visser, ME; Jones, TM; Western Oregon University, and University of Melbourne, University of Melbourne, University of Exeter, Netherlands Institute of Ecology; *hopkinsg@wou.edu*

Urbanization masks natural cues of light, noise, and temperature that affect evening cricket chorus

Artificial light at night is a pervasive pollutant that impacts diverse biological systems in myriad ways. One of the ways in which light pollution impacts organisms is through the disruption of natural circadian cycles, as many animals use these cycles to time behaviors key to fitness. A challenge of addressing the impacts of light pollution on biological timing in a natural setting is that light pollution is generally found most strongly in urban areas, which contain a multitude of factors (light, noise, temperature) that could all impact behavioral timing, and it can be difficult to parse the effects of these factors. Our ability to generalize the effects of urbanization is also hampered by logistical limitations in examining landscape-level patterns, and have traditionally focused on single species, single population comparisons. Here we

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address these challenges by examining variation in the timing of nightly calling critical for reproductive fitness of two cricket species in 14 populations across a large natural landscape of multiple urban and rural habitats. Moreover, we quantify the elements of urbanization (temperature, light, and noise) that might influence these patterns in each habitat. Our results demonstrate that both species alter their calling timing in response to natural variation in light at night, noise, and temperature, but that this variation is masked in urban areas, with resulting impacts on calling that could have important fitness consequences. Light pollution, even present at low levels, is an important management challenge in our efforts to conserve urban biodiversity.

S12-5 Horton, BM*; Ryder, TB; Moore, IT; Balakrishnan, CN; Millersville University, Bird Conservancy of the Rockies, Virginia Tech, East Carolina University; *brent.horton@millersville.edu*
Gene expression in the social behavior network of the wire-tailed manakin (Pipra filicauda) brain
The vertebrate basal forebrain and midbrain contain a set of interconnected nuclei that control social behavior. These brain regions, which are conserved across the vertebrate taxa, are collectively referred to as the vertebrate social behavior network (SBN). While it is known that nuclei (nodes) of the SBN are rich in steroid and neuropeptide activity linked to behavior, simultaneous variation in the expression of neuroendocrine genes aross several SBN nuclei has not yet been described in detail. In this study, we used RNA-seq to profile gene expression across seven brain regions representing five nodes of the SBN in male wire-tailed manakins (*Pipra filicauda*) from the Ecuadorean Amazon. Using weighted gene co-expression network analysis, we reconstructed sets of coregulated genes, showing striking patterns of variation in neuroendocrine gene expression across the SBN. We describe regional variation in gene networks comprising a broad set of hormone receptors, neuropeptides, steroidogenic enzymes, catecholamines, and other neuroendocrine signaling molecules. Our findings show heterogeneous patterns of brain gene expression across nodes of the avian SBN, highlighting the importance of region-specific sampling in studies of the neurogenetic mechanisms underlying behavior, and

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providing a foundation for future analyses of how the regulation of gene networks may mediate vertebrate social behavior.

46-9 Hou, Z*; Fuiman, LA; University of Texas at Austin, Marine Science Institute, Port Aransas, TX; *zhenxin.hou@utexas.edu*

Maternal diet affects utilization of endogenous lipids by red drum embryos and early larvae

Embryonic and early larval development and metabolism are fueled entirely by maternally derived nutritional resources (yolk and oil) before the onset of exogenous feeding. Composition of those resources depends, in part, on maternal diet. To examine the effects of maternal diet on the utilization of endogenous lipids and fatty acids, we fed red drum (*Sciaenops ocellatus*) broodstock four different diets. We sampled embryos and unfed larvae every 12 hours from 12 hours post-fertilization (hpf) until starvation (96-120 hpf) (n = 5 spawns). Differences in maternal diets did not affect egg total lipid content but resulted in distinctive egg fatty acid compositions (at 12 hpf). Rates of utilization of the oil globule between 36 and 84 hpf were significantly affected by the maternal diet, resulting in a significantly different mean oil globule size at the first feeding stage (84 hpf). Consumption rates for 14 fatty acids were significantly different among diet treatments and were proportional to their initial concentration (measured at 12 hpf). As a result, differences in fatty acid compositions associated with maternal diet diminished over time, but fatty acid profiles remained different even at later stages. In addition, egg lipid content was positively correlated with larval standard length 84 hpf (R2 = 0.40). This study suggests that maternal diet could affect energy metabolism and larval tissue composition through its effect on yolk composition. These effects could have consequences for the survival and critical physiological functions of fish larvae during the critical period of transition to exogenous feeding.

BSP-5-8 Houtz, JL*; Taff, CC; Vitousek, MN; Cornell University; *jlh498@cornell.edu*

Microbial diversity and flexibility are associated with lay date in a wild songbird

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In many temperate breeding birds, earlier breeders have higher seasonal reproductive success, but it is unclear what prevents all individuals from breeding earlier. Early breeders face variable environmental conditions, and the ability to shift phenotype to match these conditions may constrain breeding time. Microbial diversity is of known importance to host health and may influence the host's ability to adjust phenotype. Gut microbiota can also mediate adaptive changes in body mass, in addition to being influenced by diet. In this study, we tested whether cloacal microbiome diversity, or within-individual changes in microbial diversity, differ in earlier and later breeding female tree swallows (*Tachycineta bicolor*). Earlier breeders, which were heavier at first capture, had more diverse microbiomes. Birds that laid earlier lost more mass and decreased more in microbial diversity from mid incubation through early provisioning. In contrast, clutch initiation date did not predict mass change or diversity gain between early and later provisioning. Our results demonstrate that both microbial diversity and the flexibility of diversity differ by timing of breeding, and thus may serve as physiological indicators of individual quality. These results are consistent with the idea that microbial flexibility may affect an individual's ability to shift phenotype including body mass changes from incubation to provisioning, and therefore, could impact individual fitness and timing of breeding.

S4-7 Hove, AA*; Ward, JR; Hiatt, AL; Ventura, L; Neufeld, HS; Boyd, AE; Clarke, HD; Horton, JL; Murrell, ZE; Warren Wilson College, Asheville, NC, University of North Carolina, Asheville, University of Nebraska, Lincoln, NE, East Tennessee State University, Johnson City, TN, Appalachian State University, Boone, NC, University of North Carolina, Asheville, NC; *ahove@warren-wilson.edu*

Authentic research in the undergraduate classroom increases knowledge and appreciation for plants

Traditional models of undergraduate research rely on direct apprenticeship, where research scientists mentor small groups of students. This approach, however, is not readily scalable. By contrast, course-based undergraduate research experiences (CUREs) contextualize class content and provide technical training. To make authentic research opportunities accessible to broader arrays of

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students (including historically underrepresented groups), faculty from two liberal arts and two public masters'-granting institutions implemented immersive, botanically-infused, CURE modules spanning multiple scales of biological organization. Activities included measuring genetic diversity in native plant populations, estimating carbon sequestration in southern Appalachian deciduous forests, and phenological monitoring. Our goal was to improve students' awareness and appreciation of plants while honing skills in data collection, analysis, and scientific writing. For four years, we exposed hundreds of undergraduates in upper- and lower-division courses to these modules. Pre and post CURE surveys assessed attitudinal shifts and knowledge gains. Results across colleges revealed significant increases in botanical knowledge and involvement after single CURE exposures, and showed that early course experiences might yield stronger impacts. Thus, CUREs are an efficient strategy to increase engagement and knowledge for large numbers of undergraduates.

24-7 Howe, SP*; Bryant, K; Duff, A; Astley, HC; University of Akron; *sph43@zips.uakron.edu*

Robophysical models clarify the effects of body depth on fish maneuverability

Fish body shape is a complex morphological trait that affects swimming, feeding, and defense from predators. Fish exhibit a wide range of body shapes that reflect different ecological and evolutionary pressures. Deep, laterally compressed bodies have evolved multiple times in different families. Functional hypotheses explaining these trends include predator defense and increased maneuverability. While there is solid evidence that increasing body-depth helps fish avoid certain types of predators, the evidence that body shape increases a fish's maneuverability is ambiguous. We used a two-pronged approach to explore the effects of body shape on the control of maneuvers using both live fish and a robotic model that allowed us to independently vary body shape. We captured ventral video of blood-fin and black-skirt tetras performing a wide range of maneuvers and we tested the robotic model's turning ability at a range of different input kinematics across three body shapes. We found no differences in maneuverability performance between two species despite significant

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difference in body shape. Conversely, we found that deepening bodies increase the robot's ability to change direction and accelerate, though acceleration exhibits diminishing returns beyond a certain body depth. By using a robotic model, we were able to isolate the effects of body shape on maneuverability and clarify this confounded relationship. Studying the functional morphology of complex traits such as body shape and their interaction with complex behaviors like maneuverability benefit from both the broad view provided by comprehensive comparative studies, and the control of variables enabled by robophysical experiments.

84-10 Howerin, HM*; Foltz, SL; Moore, IT; Hernandez, J; Radford University, Virginia Tech, Virginia Tech; *hhowerin@radford.edu*
Noisy neighbors: how do human activity and habitat disturbance impact the nest site selection of tree swallows and eastern bluebirds?
Human-caused environmental disturbance is an ongoing issue that affects wildlife in a number of ways-especially the species we tend to live in close proximity to. Understanding the disturbances, the species they affect, and how these species are affected is essential in order to minimize potentially detrimental impacts. Both eastern bluebirds (*Sialia sialis*) and tree swallows (*Tachycineta bicolor*) readily breed near humans and will use artificial nestboxes; however, not all boxes are used equally. Last year, we compared various features of individual nestboxes and their immediate environment with both species' use of these boxes. We found that tree swallows seem to prefer boxes with less canopy cover, while bluebirds prefer boxes with less nearby pedestrian and vehicle traffic. Here, we build on this work by including additional nest boxes and measuring an additional variable highly associated with human disturbance-ambient noise. Data analysis is ongoing, but we predict that species' responses to canopy cover and human activity at nest boxes will follow the trends that we previously observed, and ambient noise will be inversely related to eastern bluebird box use as well. Our results may provide insight into the specific factors that influence species' nest site selection, particularly in areas with human disturbance, and be of practical use in conservation efforts involving artificial nest boxes.

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105-9 Huang, J*; Wang, T; Yang, X; Liang, J; Beihang University/Technical University of Munich, Beihang University, Massachusetts Institute of Technology; *huangjinguo@buaa.edu.cn*

Hydrodynamics of a biomecanical compliant flipper with skeletal skins: A numerical study

Cormorants (Phalacrocoracidae) are flipper-propelled aquatic divers which can achieve excellent takeoff capability from water surface. Computational fluid dynamics (CFD) collaborating with fluid-structure interaction has shown powerful capability for solving a variety of biomechanics problems of swimming locomotion. We implemented a flexible structural biomechanical 3-D flipper demonstrating the undulatory kinematics, in order to biomimetically synthesize realistic swimming mode. The skeletal kinematics of the flipper were constructed from the underwater swimming videos, and the soft flexible muscles were generated by the skeletal skinning algorithm. During the rapid take-off process, the cormorant used the flippers to beat the water surface at a high frequency to generate an oblique upward fluid reaction force, which cooperated with the flapping of the wings to generate lift and thrust. The cormorant's posture adjustments during take-off, such as turning and pitching, require fine movements, which require small forces and moments to be generated by the wave of the flipper. The wave state of the flipper of a cormorant is similar to that of a fish caudal fin, which can produce some anti-Carmen vortex streets that are beneficial to the state of locomotion. Meanwhile, the asymmetric flipper locomotion could initiate turn maneuvers-evidence that cormorants may use their flippers to steer during swimming. These formulations and computational procedure also apply more generally to other fluid applications, such as underwater swimming or locomotion over water surfaces.

103-10 Huang, J*; Wang, T; Liang, J; Yang, X; Beihang University, Massachusetts Institute of Technology; *huangjinguo@buaa.edu.cn*

Hydrodynamics of a biomecanical compliant lower limb with skeletal skin: A numerical study

Cormorants (Phalacrocoracidae) are flipper-propelled aquatic divers which can achieve excellent takeoff capability from water surface.

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77-3 Huene, AL*; Chen, TM; Nicotra, ML; Starzl Transplantation Institute, Center for Evolutionary Biology and Medicine, University of Pittsburgh, Pittsburgh, PA, Starzl Transplantation Institute, University of Pittsburgh, Pittsburgh, PA, Starzl Transplantation Institute, Center for Evolutionary Biology and Medicine, Department of Immunology, University of Pittsburgh, Pittsburgh, PA; *aih5@pitt.edu*

Evolution of novel self-identities by point mutation in an allorecognition molecule

Colonial marine invertebrates are capable of allorecognition—the ability to discriminate between their own tissues and those of conspecifics. In the cnidarian *Hydractinia symbiolongicarpus*, allorecognition is controlled by a single genomic region called the Allorecognition Complex (ARC), which contains at least two allorecognition genes, *Allorecognition 1* (*Alr1*),

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and *Allorecognition 2* (*Alr2*). Both encode type I transmembrane proteins with highly polymorphic extracellular domains and are capable of homophilic binding between opposing cell membranes. In Alr2, as few as six amino acid differences in the first extracellular domain are sufficient to prevent binding between otherwise identical isoforms. Here, we used ancestral sequence reconstruction and in vitro binding assays to determine how novel binding specificities evolved within a family of closely related *Alr2* alleles. Our results reveal two trajectories for the generation of a new binding specificity. In one trajectory, one amino acid change is sufficient to create a new isoform that can bind to itself but no longer binds to the ancestral isoform. In the second trajectory, four mutations ultimately lead to an allelic isoform with a novel binding specificity, but the path includes "promiscuous" intermediates that can bind to the ancestral and final isoforms. These results demonstrate it is possible to generate new functional isoforms of allorecognition proteins via relatively few mutations and have important implications for our understanding of how diversity is generated in this and other allorecognition systems.

61-14 Huey, RB; University of Washington, Seattle; *hueyrb@uw.edu*

George Gilchrist -- the Drosophila" years

George Gilchrist started out in behavioral ecology of butterflies, but soon switched to thermal biology and evolution. We began working together on *Drosophila* projects while he was a grad student with Joel Kingsolver. We soon undertook a series of shared studies of acclimation and cross-generation effects, and did a large experiment in laboratory natural selection on knock-down temperature. Later we moved to the field to study rapid evolution of geographic clines, and shared a memorable *Drosophila*-collecting trip to Chile with two Catalonian colleagues. George was the ideal collaborator. He always brought total energy and enthusiasm even to the most tedious experiments. His statistical, analytical, and graphical expertise was legendary. He was always there to share his understanding of ecology, evolution, and physiology. On a personal level, George was self-confident and took delight in defending his opinions, but he would change his views when convinced by data. He took teaching and mentorship seriously. We co-taught a course in

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Animal Diversity. George made special efforts to engage and interact with students, but with results that surprised us both. George was a friend, a mentor, and leader in science, teaching, and the good life.

BSP-11-7 Huie, JM*; Hall, KC; Summers, AP; Conway, KW; George Washington University, University of Washington, Texas A&M University; *jonathanmhuie@gmail.com*

Stick with it: convergent evolution of eco-morphotypes in clingfishes

Clingfishes (Gobiesocidae) are a diverse group of small, nearshore marine fishes. They are equipped with a ventral suctorial disc made up of elements from the pectoral and pelvic girdles. Found in a wide range of microhabitats, clingfishes use their disc to adhere to rocks, shells, macroalgae, seagrass, crinoids, and other substrates. Clingfishes have extensive morphological variation in their adhesive discs and their cranial features, that might be tied to their ecology. We use a recently published clingfish phylogeny and micro-CT based 3D geometric morphometrics to quantify morphological diversity in 72 of 181 species of clingfishes. We placed fixed and semi-landmarks on clingfish skulls and the bony elements of the adhesive disc using SlicerMorph. A remarkable aspect of clingfish diversity are the repeated transitions to living on the blades of macroalgae and seagrasses all over the world. Macroalgae/seagrass specialists have converged on similar cranial and suctorial morphologies (e.g., narrower and more elongate skulls, and narrower and taller pelvic girdles) than the rock dwelling species that are their nearest relations. Other extreme habitat specialists: two obligate crinoid species, and a single interstitial species, occupy their own regions of the morphospace.

BSP-4-5 Hulett, RE*; Loubet-Senear, K; Kimura, JO; Srivastava, M; Harvard University; *rhulett@g.harvard.edu*

Comparing nervous system development and regeneration in the acoel Hofstenia miamia

Animals capable of whole-body regeneration have been studied to understand mechanisms governing the replacement of missing cell

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types and tissues, including the myriad of cell types within the nervous system. A majority of this work has been performed utilizing the regenerative capacity of these organisms, focusing on postembryonic life-history stages. While uncovering the molecular mechanisms governing the regeneration of specific neural cell types has been extremely informative, very few species capable of whole-body regeneration have accessible embryos that allow for the functional comparison between developmental and regenerative processes with regards to the specification of neural populations. Using the acoel *Hofstenia miamia*, a member of an early diverging bilaterian lineage that is capable of robust regeneration with manipulable embryos, we sought to determine whether terminally differentiated neural cell types are governed by the same transcriptional programs during both development and regeneration. Utilizing single-cell RNA sequencing (scRNAseq) data collected during development and regeneration, we inferred putative differentiation trajectories of neural cell types. Within these differentiation trajectories, we identified candidate transcription factors that govern the transition to differentiated neural populations. We validated these markers during development and regeneration using fluorescent in situ hybridization and performed RNAi to determine the functions of these transcription factors during each process. This work compares transcriptional regulation of neural cell type specification during development and regeneration as well as the evolution of these processes.

99-7 Hunter, FK*; Kapheim, KM; Utah State University, Logan, UT; *franceskhunter@gmail.com*

Mechanisms of life history tradeoffs in a socially flexible bee

The evolution of biological complexity is rooted in life history tradeoffs, in which beneficial change in one trait (e.g., fertility) is associated with a detrimental change in another (e.g., longevity). These tradeoffs are seen at all levels of biological organization, from single-celled and multicellular organisms to groups of cooperative individuals. However, queens of social insect colonies seem to escape such tradeoffs, as they are both long-lived and highly fertile while their workers are short-lived and rarely reproduce. There are two potential mechanisms for the decoupling of tradeoffs in social insect queens; (1) queens

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have greater access to resources and are, therefore, buffered from the costs of reproduction, (2) evolutionary rewiring of endocrine networks in social insects leads to a positive association between lifespan and fecundity. The facultatively social bee *Megalopta genalis* presents a unique opportunity to study the impact of fecundity and nutrition on life history traits, as females in the wild naturally vary in reproductive and nutritional states. We compared the immune responses of *M. genalis* in states of high and low reproduction (i.e. queens/solitary mothers vs workers/newly emerged females) and high and low states of intrinsic resources (i.e. queens/lab-raised females vs solitary mothers/workers). We find that, broadly, patterns of trait investment vary in these bees depending on multiple factors. This suggests that physiology and behavior are likely determined by many shared environmental and evolutionary influences.

S11-10 Hurt, AL; Working Dogs for Conservation; *Aimee@wd4c.org*
"Anatomy" of a conservation detection dog: How an ordinary mutt becomes and elite canine conservationist
No domestic dogs are bred to be conservation detection dogs; there are no heritable, genetic traits to make certain dogs natural-born conservation detection dogs. Nevertheless, dogs have made valuable contributions over the last few decades to the preservation of endangered species, inhibiting the incursion of invasive species, and disrupting illegal wildlife trade. While it is still the rare dog who wants to make a career of working in the realm of conservation, there is much variation in the "anatomy" of a successful conservation detection dog. Their success is due to an interplay between inherent individual qualities among this diverse group of dogs and specialized training to parlay this raw capacity into accomplished conservation detection dogs. After a brief introduction to the field of conservation detection dogs, we'll discuss the suites of physical characteristics, the inherent "drives", and the roles of training, motivation, and relationship between the dog and handler which coalesce to "create" this unique dog and their contributions to wildlife conservation.

49-1 Hyacinthe, C; Harvard Medical School, Blavatnik Institute,

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Boston, MA; *carole_hyacinthe@hms.harvard.edu*

Evolution of temperature preference in the blind cavefish Astyanax mexicanus

Wild organisms live in complex environments of stratified habitats with specific chemophysical characteristics such as temperature, and develop preferences to adequate niches for setting optimal thermal body regulation. But what about biological settings when thermal environment is not a choice for living? An increasing number of species are rapidly confronted to inadequate thermal habitats consequently to climate change. Ectothermic animals such as fishes, which only rely on environmental temperatures, are particularly affected. However, little is known on how lasting thermal changes of niches affect the genetic architecture of key physiological functions and how temperature preference evolves. Thus, we propose an integrative and longitudinal approach in the lab and in the wild using a unique fish model for genetic studies: the Astyanax mexicanus. Changes in water levels isolated some individuals usually living in hot rivers of Central America (surface morph) into temperate caves. To face such a drastic environmental transformation a cave-adapted blind morph evolved, displaying striking adaptations in morphology, physiology and behavior. We question whether the temperature preference behavior evolved between the two morphs of this single species and what are the related genetic markers. We choose a quantitative trait loci approach to associate genetic variations with individual temperature preference behavior in animal freely swimming along a gradient ranging from 13° C to 37° C. In parallel, we aim at monitoring seasonal temperature variations and related chemophysical water parameters of 5 river and cave sites by deploying autonomous probes over a complete year to provide unprecedented look at the natural habitat of each Astyanax morph. Understanding thermal acclimation at a genetic level will provide insights on the altered biological settings and how mechanisms can reset these changes to a new operational level.

35-3 Iffert, RQ*; Stein, LR; University of Oklahoma, Colorado State University; *RQ.Iffert1@ou.edu*

The effects of short- and long-term environmental enrichment on exploratory behaviors in Trinidadian guppies (Poecilia reticulata)

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The effects of short- and long-term environmental enrichment on exploratory behaviors in Trinidadian guppies (*Poecilia reticulata*)
Iffert, RQ and Stein, LR University of Oklahoma, Colorado State University Rq.iffert1@ou.edu Environmental enrichment (EE) often increases positive and physiological effects on captive animals. Fish are commercially and scientifically important taxa that have been shown to benefit from EE. Here we examined the effects of both short- and long-term EE in Trinidadian guppies (*Poecilia reticulata*). In the short-term exposure to EE, female guppies were raised in standard conditions, and after reaching adulthood were moved to either an enriched or a deprived environment for two weeks. Long-term exposure guppies were reared from birth for 12 weeks (until sexual maturity) in either an enriched or deprived environment. We then assessed neophobic and exploratory behaviors in standard assays. Our results suggest that fish given EE were more exploratory, regardless of timescales, although males showed a more pronounced change in exploratory behaviors than females. Additionally, enriched females were more exploratory than deprived across timescales, but females with long-term exposure to EE were faster to approach a novel object than those that had received only short-term exposure. EE is encouraged to improve the welfare of captive animals. Here we highlight that EE influenced neophobic and exploratory behaviors in guppies, even after only two weeks. Our results highlight the need for assessing the influences of EE in captivity, in particular for researchers interested in recreating "natural" behaviors in their laboratory studies.

72-8 Iijima, M*; Munteanu, VD; Kinsey, CT; Elsey, RM; Blob, RW; Clemson University, Clemson, Louisiana Department of Wildlife and Fisheries, Baton Rouge; *miijima8@gmail.com*
Ontogenetic changes in limb kinematics, forces, and joint moments in American alligators
For tetrapods that use parasagittal limb posture, many studies have shown that locomotor patterns change as body size increases. However, little is known about such changes for animals using non-parasagittal limb posture. Crocodylians are the largest living quadrupeds with non-parasagittal limb posture, thus, they provide an opportunity to study how non-parasagittal locomotion changes as size increases. To test for such changes, we used six juvenile

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American alligators (small: n = 3, 0.23-0.25 kg; large: n = 3, 1.40-2.05 kg) to characterize normalized stride parameters, joint angles, single-limb forces, and joint moments as they walked across a force platform. Large juveniles walked slower and with shorter steps. Normalized peak vertical forces were similar in fore- and hindlimbs of small juveniles, but hindlimbs showed greater vertical forces than forelimbs in large juveniles. In addition, the two size classes used similar forelimb kinematics, but the hindlimbs showed more erect joint angles in large juveniles than in small ones. These differences in kinematics and locomotor forces may relate to a posterior shift in the center of mass (CoM) between small and large juveniles. They also may have consequences for skeletal loading, as the larger forelimb vertical forces and more abducted hip of small juveniles produce greater normalized moments for shoulder adduction, elbow flexion, and wrist flexion in the forelimbs, and hip adduction in the hindlimbs. Previous studies suggested that upright locomotion led to higher bone strains among large juveniles. This makes their ontogenetic shift to more upright posture puzzling, and calls for comparisons of limb bone loads between small and large alligators.

41-12 Ilyas, Z; Brar, N; Shin, J; Hansen, AK; Telemeco, RS; Müller, UK*; CSU Fresno; *umuller@csufresno.edu*

How is COVID19 affecting scientific publishing - a study of a conference-proceedings journal

Evidence is mounting that COVID 19 is decreasing workplace productivity and has increased inequalities in scholarly productivity. In this study we focus on a conference-proceedings journal (Integrative and Comparative Biology) to assess if COVID 19 is reducing research outputs and is disproportionally affecting scholars whose professional and personal lives are more likely to be negatively impacted by the effects of COVID 19. We hypothesized that the number of publications will decrease as some authors are unable to follow through on their prior commitment to submit a manuscript; and that these authors are more likely to come from groups who face increased care-giver responsibilities, increased teaching loads, and are living in geographic areas with higher infection rates and stricter quarantine rules, such as women, instructors at teaching-intensive institutions, and authors living

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in US states with high infection rates. We predicted that affected groups will submit fewer papers as first or corresponding author, and will experience more publication delays, evident in longer times between symposium presentation and corresponding manuscript going to press. To test our hypotheses, we compared scientific publications from 2019 and 2020. Our preliminary analysis found that our data were largely consistent with our predictions. We found, for example, that the number of submitted manuscripts decreased and that the time between conference presentation and the corresponding manuscript going to press increased.

2-14 Inäbnit, T*; Dennis, A; University of Potsdam; *inaebnit.thomas@gmail.com*

The mitochondrial genome of Melampus bidentatus (Panpulmonata, Ellobioidea)

Melampus bidentatus is a complex of three cryptic species that are an important component of the salt marsh communities along the North American east coast and the Gulf of Mexico. We assembled the mitochondrial genome of *Melampus bidentatus* North from Illumina short read data using NovoPlasty and annotated it on the MITOS webserver. Additional sequences were downloaded from GenBank. The mitochondrial genome contains 36 genes, 24 on the forward strand and 12 on the reverse strand, with one tRNA gene that is usually present in Ellobioidea missing. *Melampus bidentatus* is one of three currently known Ellobioid species (one, *Pedipes pedipes*, related, the other, *Myosotella myosotis*, less so) who deviate from the otherwise uniform gene order within the Superfamily. These three species are also recovered outside the rest of the Ellobioidea in all mitogenome based phylogenies, which is not supported by other phylogenetic or morphological studies.

25-1 Ingle, DN*; Porter, ME; Texas A&M University at Galveston, Galveston, TX, Florida Atlantic University, Boca Raton, FL; *danielleningle@gmail.com*

The microarchitecture and mechanical properties of cetacean vertebral trabecular bone

Swimming activity varies among cetaceans; interspecific differences in vertebral column morphology determine varying caudal oscillatory

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modes, while deep-diving species have been shown to glide a greater proportion of the time compared to their shallow-diving counterparts. We categorized 10 cetacean species (Families Delphinidae and Kogiidae) into functional groups determined by swimming modes (rigid vs. flexible torso) and diving behavior (shallow vs. deep). Our goals were to: (1) quantify the form and function of trabecular bone, a dynamic tissue, among functional groups and regions of the vertebral column, and (2) compare cetacean trabecular bone structure with previous findings on terrestrial mammals. Vertebrae were obtained from necropsies and dissected from four regions of the vertebral column. Vertebrae were µCT scanned in a Bruker SkyScan 1173, and microarchitectural parameters (bone volume fraction and degree of anisotropy) were quantified. After scanning, 6mm bone cubes were cut from vertebrae and compression-tested at 2 mm/min using an Instron E1000 material tester. Mechanical properties (yield strength and stiffness) were calculated using stress-strain curves. Rigid-torso, shallow-diving cetaceans had the greatest yield strength, stiffness, and bone volume fraction of all functional groups, suggesting relatively greater loading of the vertebral column. Rigid-torso species had a greater degree of anisotropy than flexible-torso animals, independent of habitual diving behavior. Increasing bone volume fraction was a strong predictor for increases in yield strength and stiffness. We found that cetacean vertebral trabecular bone had greater microarchitectural variables compared to previously investigated terrestrial mammals, which may reflect an evolutionary adaptation to a non-weight bearing environment.

S1-8 Injaian, AS*; Uehling, JJ; Taff, CC; Vitousek, MN; Cornell University and University of Georgia, Cornell University; *inja@uga.edu*

Experimental investigation of the effects of artificial light at night on avian parental behavior, offspring glucocorticoids, and reproductive success

Artificial light at night (hereafter 'ALAN') affects 88% of the land area in Europe and almost half of the land area in the US, with even rural areas exposed to lights from agricultural and industrial buildings. We know little about the impacts of ALAN on wildlife behavior and physiology, yet altered energy expenditure or

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stress physiology during the breeding period could reduce reproductive success and have conservation implications. Here, we experimentally exposed adult female and nestling tree swallows (Tachycineta bicolor) to ALAN. We then measured the effects of ALAN or control conditions on parental behavior (provisioning rate), nestling physiology (corticosterone levels), and reproductive success (proportion of eggs hatched and nestlings fledged). Our results showed that ALAN-exposed nestlings had slightly reduced baseline and increased stress-induced corticosterone, compared to control nestlings. ALAN-exposed nestlings also showed greater down-regulation in circulating corticosterone (i.e. negative feedback). Additionally, ALAN-exposed females provisioned their nestlings less frequently. Finally, ALAN was negatively associated with the proportion of eggs hatched, but not the proportion of nestlings fledged. While our results suggest a modest effect of ALAN exposure on behavior and physiology, and possible effects on hatching success, these changes did not translate to differences in fledging success. Therefore, ALAN exposure may not affect population health in this species.

47-5 Ivashkin, EG*; Voronezhskaya, EE; Gribble, KE; MBL, Woods Hole, MA; IEE RAS, Moscow, Russia, IDB RAS, Moscow, Russia, MBL, Woods Hole, MA; *eivashkin@mbl.edu*

Molecular organization of rotifer neurogenesis: not a worm and not a fly

The molecular mechanisms underlying the formation and patterning of the bilaterian nervous system (NS) have been investigated primarily in lophotrochozoans, ecdysozoans, and deuterostomes, while gnathifers remain largely unexplored. Gnathifera (the 4th largest clade of Bilateria) are thought to be early diverging Spiralia and include enigmatic animals, the evolution of which is unclear. Rotifers are an experimentally tractable phylum of Gnathifera; understanding their NS development could shed light on the early evolutionary history of the Protostomia. We used HCR fluorescent *in situ* hybridization to assay the expression of the monogonont *Brachionus manjavacas* orthologs of neurogenic genes including *SoxB1*, *Elav*, *Ascl*, *Ngn*, *Pou4*, and *Coe*; neuronal markers including *Syt1* and *TrpV*; and patterning markers including *FoxQ2*, *Six3/6* and *Eve*, in combination with live-imaging.

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The neuroblasts divide prior to ingression in the plane of the epithelium. *SoxB1* is evident in part of the neuroectoderm, later neuroblasts, and some non-neural cells of neuroectodermal origin; it does not switch off after precursor commitment. *Ngn* marks only few cells prior to ingression. *Elav* is not restricted to neuroblasts and neurons; in some neurons, it is expressed only at late stages of differentiation. *Ascl* appears in precursors of the stomatogastric NS and followed by *Pou4*. *Coe* marks the origin of the dorsal antenna (DA) within the region surrounded by the *FoxQ2* and *Six3/6* expression in the head. Cells of the DA also express the sensory marker *TrpV*. These features, in combination with the observed morphology, suggest that the DA is a homolog of the apical organ. *Coe*+ cells migrate to the trunk and develop into the earliest posterior neurons, becoming the lateral nerve and initiating the cerebral ganglion, suggesting their homology to pioneer neurons. *Syt1* is pan-neuronal and occurs in some migrating cells. Rotifer neurogenesis thus possesses a combination of features characteristic for other Protostomia, with additional traits unique to Bilateria. Supported by RFBR grant 19-04-01181 and the Owens Family Foundation.

BSP-10-8 Iverson, ENK*; Havird, JC; The University of Texas at Austin; *erik.iverson@utexas.edu*

How to get high: Positive selection on mitochondrial genes in high-elevation species

Species turnover within a genus is often observed across climatic gradients. Mitochondrial (mt) divergence between species is usually thought to be a neutral process, but mt haplotypes within and among species often segregate with climatic factors known to impact mitochondrial function. For this reason, climatically-driven evolution of the mt genome might be an important driver of ecological speciation, and, through epistatic interactions with the nuclear genome, a driver of post-zygotic isolation. Although studies frequently report the signature of positive selection on particular mt genes in high-elevation species and posit adaptive explanations, there is little evidence to say whether elevation consistently causes selection across mt genes and in all taxa. To investigate how elevation shapes mt divergence, we analyzed the signature of natural selection on the protein-coding regions of the

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mt genome. We obtained mitogenomes from 186 terrestrial vertebrates consisting of sister taxa from high and low elevations at similar latitudes as well as low-elevation outgroups. Ratios of nonsynonymous to synonymous substitutions (dN/dS), a measure of positive selection, generally increased in high-elevation species. However, this difference was only significant in cases where a model of evolution estimating the same dN/dS value for the low-elevation and outgroup taxa was preferred to one with more parameters. This suggests that there is positive selection on the mitochondrial genes of high-elevation vertebrates, particularly where they have evolved from within consistently lower-elevation clades. We discuss implications of these findings for environmental adaptation, speciation, and climate change, as well as refinements in methodology and an exploration of mitochondrial responses to elevation in invertebrates.

21-2 Iwanicki, T*; DeTurk, H; Porter, ML; University of Hawai'i at Mānoa; *iwanicki@hawaii.edu*

Turning up the lights: Ocean acidification may increase light intensity of secretory bioluminescent signaling

Bioluminescence - when a living organism produces light by oxidizing a luciferin with luciferase - is a prevalent phenomenon in the world oceans. As many as 75% of organisms in the pelagic are capable of bioluminescence, which is used for offense, defense, and courtship behaviors. Having evolved independently upwards of 50 times, there are a correspondingly large number of factors that can influence the color, intensity, or kinetics of the bioluminescence reaction. One factor often described in the primary literature on novel luciferin-luciferase reactions is the pH of the reaction media. For internally emitting organisms, e.g., scintillon-bearing dinoflagellates, changes in cellular pH are used to trigger bioluminescence; however, secreting organisms must rely on the ocean as their reaction buffer. Anthropogenic climate change brings with it many unanticipated consequences. Under the IPCC worst-case scenario (RCP8.5), the average ocean pH will decrease from its pre-industrial average of 8.2 to 7.7 by the end of the 21st century. Under these conditions, secretory bioluminescence systems may be affected by this change in the reaction medium, ocean water pH. This meta-analysis surveyed 365 primary literature papers, books,

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and chapters for data on the impact of pH ranging from 7.7-8.2 on native luciferase-luciferin bioluminescence reactions. This study covers a taxonomically diverse group including Bacteria, Dinoflagellata, Cnidaria, Mollusca, Arthropoda, Ctenophora, and Chordata. Preliminary data suggest that secretory bioluminescence systems will increase light intensity or total quantum yield by approximately 5-15%. The rapid (in an evolutionary timescale) increase in light intensity would have a multitude of knock-on effects for the sensory ecology of marine communities.

98-5 Jacisin, JJ*; Fielder, C; Hibbitts, TJ; Ryberg, WA; Walkup, DK; Meik, JM; Lawing, AM; Texas A&M University, Tarleton State University; *jjacisin3@tamu.edu*

Morphological variation of cranial elements in the western massasauga (Sistrurus tergeminus)

To investigate morphological variation of cranial elements in western massasauga (*Sistrurus tergeminus*) populations, we obtained microCT scans from 121 wet-preserved individuals representing 10 populations across the U.S. and Mexico. We developed landmark schemes of dorsal and lateral skull orientations that capture major aspects of skull shape and account for snake skull kinesis, then Procrustes superimposed landmarks to translate, rotate, and scale the schemes. We ordinated the landmarks with a principal components analysis and used linear discriminant functions to test the reliability of taxonomic, population, and sex assignments. PC1 (~42.9% explained variance) represents an axis of nasal and premaxilla compression and braincase and occipital region elongation, potentially associated with among-population dietary differences. PC2 (~9.7% explained variance) represents lengthening of the supratemporal bone, associated with viperid striking and feeding mechanisms, in northern populations. Discriminant functions classified individuals to *S.t. tergeminus* and *S.t. edwardsii* with 77.1% and 62.8% accuracy, respectively. Males and females were less accurate, with 66.7% and 49.0% accuracy, respectively, suggesting more geographic variation than sexual dimorphism. The classification accuracy of specific populations was low, at 28.1%, however, populations were assigned to other geographically close populations. Further investigation into the differences between diet and other ecological factors across the geographic

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distribution of *S. tergeminus* populations will help reveal the specific factors associated with identified morphological differences.

79-5 Jackson, EK*; Elmore, JA; Loss, SR; Winger, BM; Dakin, R; Carleton University , Oklahoma State University , University of Michigan, Carleton University; *ErinKJackson@cmail.carleton.ca*

Morphology, vision, and the risk of collision mortality in birds

Collisions with buildings are a major source of mortality for wild birds, but these events are difficult to observe. As a result, the mechanistic causes of collision mortality are poorly understood. Here, we evaluate whether sensory and biomechanical traits can explain why some species are more collision-prone than others. We first examined concordance of species vulnerability estimates across previous North American studies to determine whether these estimates are repeatable, and whether vulnerability is more similar among closely-related species. We found moderate concordance and phylogenetic signal, indicating that some bird species are consistently more collision-prone than others. We next tested whether morphological traits related to flight performance and sensory guidance explain these differences among species. Our comparative analysis shows that two traits primarily predict collision vulnerability within passerines: relative beak length and relative wing length. Small passerine species with relatively short wings and those with relatively long beaks are more collision-prone. This suggests that flight control may influence collision risk in a size-dependent manner. Together, these findings can help inform mitigation strategies and predict which species will be most at risk in other regions.

31-6 Jacobs, G*; Shenoy, K; Srinivasan, M; Cooper, R; University of Kentucky; *Grace.Jacobs@uky.edu*

Social interactions of intraspecies pairs of Australian crayfish Cherax quadricarinatus and interspecies pairs of Louisiana red swamp crayfish Procambarus clarkii: Invasive species alert

The Australian crayfish (*Cherax quadricarinatus*) has become increasingly common in the aquaculture industry due to its larger size and tolerance of environmental conditions such as temperature,

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hypoxia, and water quality. There is a high risk of the species being introduced into the wild, as aquaculture ponds are commonly in association with natural streams and ponds. Likewise, public use, and disposal, of crustaceans is known to not be tightly controlled which could lead to competitive interactions with other widespread native species. Therefore, we are interested in examining the behavioral nature of *C. quadricarinatus* in the intraspecies pairing as well as interspecies pairing with a well-established model of an aggressive native crayfish (*P. clarkii*). To accomplish this, crayfish were isolated for 2 weeks and then paired for 20 min with video monitoring. Similar sized *C. quadricarinatus* were used for pairing from small (4-5 cm body length) to large (~15 cm). Only large *C. quadricarinatus* and large *P. clarkii* were paired. Thus far, small *C. quadricarinatus* are more aggressive in their intraspecies pairings than either the large *C. quadricarinatus* or the *P. clarkii*. The results of this ongoing investigation will establish the social nature of the previously unstudied *C. quadricarinatus*.

56-2 Jankauski, MA*; Casey, C; Busby, K; Buchmann, S; Montana State University, Dept. of Mechanical and Industrial Engineering, Montana State University, Dept. of Mechanical and Industrial Engi, University of Arizona, Dept. of Ecology & Evolutionary Biology, University of Arizona, Dept. of Ecology & Evolutionary Biology; *mark.jankauski@montana.edu*

Force production and thoracic vibrations during defensive buzzing in carpenter bees (Xylocopa: apidae)

Bees use thorax vibration to achieve flight, facilitate pollination, and communicate information. When threatened, many bee species buzz to warn predators of an impending sting; this behavior is referred to as defensive buzzing. Force production and thoracic vibrations have been evaluated during flight, but little is known about defensive buzzing. We measured the directional force production and thoracic vibration velocity during defensive buzzing. We mounted carpenter bees *Xylocopa californica* to a carbon fiber post fixed to a high-sensitivity transducer to measure force production. Thorax vibration velocity was measured via laser vibrometry. Root-mean-squared (RMS) force production was 25.86 ± 9.6 mN along the dorsal-ventral axis, 15.37 ± 6.6 mN along the

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anterior-posterior axis, and 8.72 ± 3.1 mN along the medial-lateral axis. This suggests the bee is vibrating with axes aligned with its indirect flight muscles. RMS thorax velocity was 20.86 ± 6.5 mm/s and occurred at a fundamental frequency of 95.9 ± 19.4 Hz. Individual bees adjusted their primary thorax vibration frequency approximately 15% from the average. Because force components exhibit pronounced integer harmonics of the primary thorax vibration frequency, bees can excite a wide frequency range of nearly 500 Hz. This ability may be useful during behaviors such as buzz pollination, where the insect may benefit from resonating a flowers' pored anther. This work suggests that the dynamics of the bee's thorax differ between defensive buzzes and other behaviors.

14-7 Jardón, L*; Stankowich, T; California State University - Long Beach; *Lizbeth.Jardon@student.csulb.edu*

Comparison of bite force and skull dimensions between urban and rural coyotes (Canis latrans)

Humans are capable of drastically altering their environment within a relatively short time frame, turning vast natural landscapes into bustling cities. Few organisms can adapt quickly enough to survive these changes; those who do often subsidize their diet with anthropogenic food since an animal's natural food source may not be readily available. A species with populations living in both urban and rural environments may, therefore, experience musculoskeletal changes in response to different selective pressures stemming from food diversity, availability, and acquisition difficulty. Here, we compare skull dimensions and bite force of coyotes (*Canis latrans*) from an urban population (Greater Los Angeles) with those from a rural population (Fresno County). Upper jaw length and width, mastication muscle masses, lower jaw lever length, and skull length measurements were recorded for each specimen; and upper jaw length/width ratio and bite force at the carnassial molar and lower canine were calculated. Current findings indicate urban coyotes have greater variation in upper jaw shape, with statistically nonsignificant trends towards wider snouts, longer skulls and a stronger molar bite force in urban coyotes. While more data is needed, trends suggest urban environments favor the development or evolution of powerful bites to allow for feeding on domestic pets.

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15-7 Jean-Joseph, HG*; Wacker, K; Kotrschal, K; Dept. of Behavioral and Cognitive Biology, Univ. of Vienna & Wolf Science Center, Domestication Lab, Konrad-Lorenz Institute of Ethology, Univ. of Veterinary Medicine, Vienna, Austria, Wolf Science Center, Domestication Lab, Konrad-Lorenz Institute of Ethology, Univ. of Veterinary Medicine, Vienna, Austria & Faculty of Biology, Ludwig-Maximilian-Univ. of Munich,
Germany; *hillary.jean.joseph@wolfscience.at*

Circannual time budget of equally raised wolves and dogs

Due to domestication, dog behavior differs from wolf behavior, influencing the time they engage in different types of behavior. At the Wolf Science Center (WSC), wolves and mongrel dogs are raised and kept in a similar way: living in packs in outside enclosures all year round and receiving a similar amount of human interaction. This makes the WSC a perfect place to compare the daily time-budgets of wolves and dogs. In search for intrinsic behavioral differences between wolves and dogs seven wolf packs and four dog packs were observed over a year (n=1567). We focused on resting, foraging, etc., and calculated the proportion of time they spend on each of their activities. We expected dogs to be more active than wolves due to domestication, which would have relaxed the need to spare energy for essential activities. However, wolves and dogs did not differ much in their time budgets. Moreover, dogs and wolves were more active when humans were present at the enclosure; however, dogs were more active than wolves in this situation. We conclude there is no substantial change in intrinsic behavioral motivation due to domestication in dogs, except for their responses to human presence. This suggests that humans are social Zeitgeber for dogs, but not so much for equally socialized wolves.

97-4 Jenkins, KM*; Bhullar, BAS; Yale University, Department of Earth and Planetary Sciences, New Haven,
CT; *kelsey.jenkins@yale.edu*

The role of the stapes in the evolution of reptilian hearing

In crown reptiles, the stapes is a slender bone capable of transmitting high-frequency sounds from the outer tympanum to the inner ear. However, this element is larger and more robust in stem-

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group and early crown amniotes. In those taxa it likely played a greater role in structural support of the cranium than in transmitting sound. The early amniote stapes has been suggested to have been capable at most of transmitting low frequency sounds. This, in conjunction with quadrate morphology, caused previous workers to categorize stem and crown reptiles in a binary manner when discussing the evolution of hearing: impedance-matching or not. This binary classification implies a rapid transition between states. There is, however, a paucity of transitional fossil stapedes; our understanding of the evolutionary transition from low-frequency to high-frequency hearing in reptiles is limited. Our discovery of stapedes in near-crown stem-reptiles suggests that the evolution of this trait was not as binary as previously implied. The stapedes of two archaic diapsid stem-reptiles, Palacrodon sp. and Avicranium renestoi, are minute elements that show a transitional morphology between the robust, supportive stapedes of earlier stem-reptiles and the slender, elongate morphology of crown reptiles. Moreover, we find that the stapes of Youngina capensis, one of the most crownward stem-reptiles, is much more elongate than those of earlier stem-reptiles, despite frequently having been described as robust. The stapedial morphologies of these taxa suggest they were capable of hearing higher frequencies than more basal taxa. We posit therefore that stapedial evolution was more gradual than previously appreciated, and that middle ear specializations for higher-pitched hearing may have preceded external ear (tympano-quadrate) specializations.

80-12 Jeong, SW*; Rice, NA; Daley, MA; Nishikawa, KC; Northern Arizona University, Center for Bioengineering Innovation, Flagstaff, AZ, Northern Arizona University, College of Health and Human Services, Phoenix, AZ, University of California, Irvine, School of Biological Sciences, Irvine, CA, Northern Arizona University, Department of Biological Sciences, Flagstaff, AZ; *Kiisa.Nishikawa@nau.edu*

A new muscle model including a titin element

Hill models based on isometric force-length (FLR) and isotonic force-velocity relationship (FVR) fail to predict muscle force under dynamic conditions, due in part to absence of history-dependence of muscle force. To overcome this limitation, a new

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muscle model was developed with a titin element, based on titin-actin interactions in active muscle. The titin element wraps around a pulley, connecting to a contractile element in both series and parallel to simulate history-dependent forces. In this study, we aimed to test the ability of the new muscle model and a 12-parameter Hill model to predict forces observed during dynamic length changes. The strain of *ex vivo* mouse EDL was controlled using *in vivo* strain trajectories measured from guinea fowl LG during treadmill running over obstacles. Five strain trajectories (2 different upward strides, 1 downward stride, 1 level stride and 1 sine wave) and three activation patterns (Normal (*in-vivo*); Late (~12.5ms later start); and Long (duration + 33ms)) were used. The parameter set was trained using the 'level stride' strain trajectory and 'Long' activation and was tested on the other trials. The mean r^2 (0.73±0.12) was significantly lower for the Hill model (paired *t*-test, $p < 0.01$) than for the titin model (mean $r^2 = 0.85 \pm 0.07$). The result demonstrates that the new muscle model including a titin element predicts the dynamic variability of muscle force with higher accuracy than the Hill model based on FLR and FVR for strain trajectories typical of *in vivo* locomotion, and supports the idea that active titin-actin interactions contribute to muscle mechanics.

S11-7 Jimenez, AG; Colgate University; *ajimenez@colgate.edu*
The physiological conundrum that is the domestic dog
Across Mammalia, body size and lifespan are positively correlated. However, in domestic dogs, the opposite is true: small dogs have longer lives compared with large dogs. Here, I will, first, present literature-based data on life-history traits that may affect dog lifespan, including adaptations at the whole-organism, and organ-level. At the cellular level, I will describe mechanisms that differ across size classes of dogs, including increases in aerobic metabolism with age, and increases in glycolytic metabolic rates in large breed dogs across their lifespan, a phenotype which could increase the likelihood of large breed dogs developing cancer. Because oxidative stress is a byproduct of aerobic metabolism, I will also present data on oxidative stress in dogs that point to the fact that small breeds of dogs accumulate significantly more lipid peroxidation damage (LPO) in their plasma compared with large

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breed dogs, in opposition to predicted lifespan predictions. And, that wild canids have increased antioxidant concentrations compared with domestic dogs, which may aid in explaining why wild canids have longer lifespans than similar-sized domestic dogs. To address potential interventions to extend lifespan in domestic dogs, I will describe experimental alterations to cellular architecture to test the "membrane pacemaker" hypotheses of metabolism and aging. This hypothesis suggests that increased lipid unsaturation and large amounts of polyunsaturated fatty acids (PUFAs) in cell membranes can increase cellular metabolic rates and oxidative damage, leading to potential decreased longevity. By decreasing total saturation of primary fibroblast cells from small and large breed dogs, we found that aerobic metabolism decreased compared with untreated cells, a trait associated with longer lifespans.

BSP-2-4 Jimenez, YE*; Marsh, RL; Brainerd, EL; Brown University; *yordano_jimenez@brown.edu*

A biomechanical paradox in the dual-function axial musculature of fish

Muscle is the powerhouse for a panoply of animal motions, yet peak muscle performance is constrained to a narrow set of conditions. As a result, muscles are often thought of as being adapted for peak performance for specific behaviors. This has given rise to the notion that fish axial muscles are specifically adapted for producing explosive locomotor behaviors. However, fish also use their locomotor muscles to generate over 90% of the power for suction feeding. This raises a critical issue: what impact do these two very different behaviors have on muscle performance? For example, a well-studied form-function relationship in fishes has been the mediolateral strain gradient that forms in the musculature during axial locomotion, where muscle on opposite sides of the body undergoes the highest tensile and compressive strains. Under these conditions, only a thin section of muscle could shorten at velocities appropriate for maximizing power. Prior work has identified a complex morphological solution to this constraint, but the emerging dual-function paradigm raises the question: does such a strain gradient exist for suction feeding? We measured length changes in different regions of the epaxial musculature to determine whether these motions occurring in different planes

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(lateral flexion versus dorsiflexion) produce different strain patterns within the muscle. We found that suction feeding produces a linear strain gradient that, unlike the gradient for locomotion, occurs along the dorsoventral axis. Our discovery of these orthogonal strain gradients presents a paradox: bluegill should not be able to attain maximal muscle power output in both swimming and feeding, yet there is evidence to suggest that they do. Future work solving this paradox may produce new insights into the structure and function of axial muscles in fishes.

S11-1 Jimenez, AG*; Bryce, C; Colgate University; *ajimenez@colgate.edu*

Biology's best friend: Bridging disciplinary gaps to advance canine science

Dogs (*Canis familiaris*) are an ideal model for inter-disciplinary science. From their beginnings, the evolutionary history of dogs contains unpredicted effects across all levels of biological organization. These include diversification from highly social, pack-dwelling wild carnivores (extant grey wolves), to increased dependence on humans (domestication), and modern colonization our homes and our beds (inter-species bonding). The history and global abundance of this single species provides a rich interdisciplinary opportunity for research. This young, emerging field of "canine science" is comprised of diverse biological disciplines including evolution, genetics, physiology, cognition, behavior, and ecology, drawing on studies of both natural and experimental systems and scaling across all levels of biological organization, from genomes to ecosystems. However, limited connections bridge the various fields associated with canine science and there has been a growing interest over the past few years to integrate the insights from genomic evolution with those from ecophysiology and ecology to gain a more biologically-comprehensive perspective of this species. In particular, canine research that is integrative, mechanistic, and/or ecological in nature has been generally underrepresented. To address these developing interests in the community, this symposium will bring together scientists working in diverse realms of canine research to address noteworthy topics in dog biology. The speakers include experts in dog evolution, genetics, cognition, and physiological ecology. By presenting this combination of expertise,

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we hope to inform the community of the importance of canine biology, foster collaborations across diverse disciplines, rethink familiar themes, and develop new and tools for canine research so as to collaboratively advance this field.

60-7 Jiménez-Padilla, Y*; Lachance, M-A; Sinclair, BJ; Western University, London, Ontario, Canada; *yjimenez@uwo.ca*
Live yeasts accelerate Drosophila melanogaster larval development
The digestive tract of most animals is inhabited by a complex community of microbes, including bacteria, yeasts, protozoans, and viruses. This gut microbiota influences host physiology from metabolism and immunity to behavior. Bacteria-focused research is more abundant in the published literature when compared to other microbes. *Drosophila melanogaster*, with its relatively simple gut microbiota comprised mainly of bacteria and yeasts, is an excellent model for studying the lesser explored role of yeasts on host physiology. Yeasts are often provided to flies as nutrients, but their role in the gut microbiota is poorly understood. I studied the effects of *Saccharomyces cerevisiae* (the yeast commonly used in lab settings) and *Lachancea kluyveri* (a yeast originally isolated from the gut of *Drosophila* spp.) on fly development. I reared *D. melanogaster* as axenic (free of microbes) and gnotobiotic (with a known yeast species in their gut) flies and recorded their pupation and eclosion times. Both yeasts on their own reduced larval development time by 20 % when compared to axenic (free of microbes) flies, recreating the effect of having an intact microbiota. The effect is not purely dietary, as heat-killed yeasts and nutritional supplements (amino acids and B-vitamins) reduce development time only by c. 10 %. Future studies will focus on identifying the mechanisms underlying the effects of gut yeasts on *D. melanogaster* physiology.

69-6 Jin, B; Luo, H; Ding, Y*; Beijing Computational Science Research Center , Vanderbilt University; *dingyang@csrc.ac.cn*
Swimming of the mosquito larva: principles and tricks of locomotion at intermediate Reynolds numbers
For swimming, mosquito larva (*Chironomus plumosus*) bends its cylindrical body into nearly a circle from one side to the other

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sequentially and generates a trajectory that resembles figure-of-eight. This gait is drastically different from the undulatory gait used by other slender-body organisms, such as eel and nematode. We developed a numerical model of the larva with prescribed body deformation and coupled it with computational fluid dynamics. We found that, in contrast to undulatory swimmers who try to reduce rotation all the time to align their propulsion with the direction of motion, the mosquito larva purposely generates a significant rotation and timely generate the propulsion forces when the propulsion forces align with the direction of motion. The mosquito larva also modulates the speed of body deformation to increase the propulsion force since force scales more than linear to speed at intermediate Reynolds numbers. As a result, the swimming speed is greater than the speed of the undulatory gait in the same condition. Although the energetic efficiency of the figure-of-eight gait is low, the power is small compared to the larva's metabolic rate.

66-4 Johns, W*; Davis, L; Jankauski, M; Montana State University, Bozeman MT, Montana State University, Bozeman, MT; *wrj.msu@gmail.com*

Reconstructing full-field flapping wing dynamics from sparse measurements

Wing deformation during flight affects insect's aerodynamic force production and energetic efficiency. However, measuring wing deformation in flying insects is challenging as many points must be tracked over the wing's surface to resolve its instantaneous shape. Some insects have mechano-receptors in their wings which detect wing strain and strain time histories. This strain feedback is believed to be used to realize closed-loop altitude control. Inspired by these sensing mechanisms, we propose a novel method to resolve instantaneous wing shape using a low number of measurements. We use a physics-based reconstruction technique called System Equivalent Reduction Expansion Process with sparse strain measurements to estimate the full field strain and deformation of the wing. Sensor placement is informed by the Weighted Normalized Displacement Method. The method positions the sensors at locations where the strain contributions of different modes are distinguishable and where the strain signal is high,

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thereby reducing the influence of noise. The method is validated by flapping a paper wing with three mounted strain sensors and using two of the measurements to estimate the third. We then extend to a more realistic insect wing in numerical simulation. The work demonstrates that full field displacement can be estimated from sparse strain or displacement measurement, and it is shown that additional sensors spatially average measurement noise to improve reconstruction accuracy. This research provides a technique to overcome some challenges of measuring full-field dynamics in flying insects, and it offers a framework for strain-based sensing that may be advantageous for the design of insect-inspired flapping robots.

94-6 Johnsen, S*; Lohmann, KL; Warrant, EJ; Duke University, University of North Carolina at Chapel Hill, Lund University; *sjohnsen@duke.edu*

The wobbly compass needle: are the peculiarities of magnetic orientation behavior partially explained by low signal relative to noise?

Diverse organisms use Earth's magnetic field as a cue in orientation and navigation. Nevertheless, eliciting magnetic orientation responses reliably, either in laboratory or natural settings, is often difficult. Many species appear to preferentially exploit non-magnetic cues if they are available, suggesting that the magnetic sense often serves as a redundant or 'backup' source of information. This raises an interesting paradox: Earth's magnetic field appears to be more pervasive and reliable than almost any other navigational cue. Why then do animals not rely almost exclusively on the geomagnetic field, while ignoring or downplaying other cues? Here we explore a possible explanation: that the magnetic sense of animals is 'noisy', in that the magnetic signal is small relative to thermal and receptor noise. Magnetic receptors are thus unable to instantaneously acquire magnetic information that is highly precise or accurate. We speculate that extensive time-averaging and/or other higher-order neural processing of magnetic information is required, rendering the magnetic sense inefficient relative to alternative cues that can be detected faster and with less effort. This interpretation is consistent with experimental results suggesting a long time-course

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for magnetic compass and map responses in some animals. Despite possible limitations, magnetoreception may be maintained by natural selection because the geomagnetic field is sometimes the only source of directional and/or positional information available.

58-6 Johnson, KH*; Dobkowski, KA; Bates College; *kjohnso4@bates.edu*
Feeding preferences of Pugettia gracilis (Graceful Kelp Crab)
The feeding preferences of graceful kelp crabs (*Pugettia gracilis*), a species that ranges from Alaska to Baja California, are widely unknown. To quantify their feeding preferences, we used 12 graceful kelp crabs collected from four sites on San Juan Island, Washington and ran choice and no choice experiments using *Nereocystis leutkeana* and *Sargassum muticum*. These experiments showed that *P. gracilis* prefer to consume *Nereocystis leutkeana* over *Sargassum muticum* in choice experiments. In no choice experiments, *P. gracilis* ate equal amounts of *Nereocystis leutkeana* and *Sargassum muticum*, indicating that the crabs can exploit both food options. As ocean conditions and environments change, the pressures placed on *P. gracilis* will change as well. Food sources may shift, predation may vary, and other unknown problems may arise. With changing ocean conditions and environments, this study demonstrates the diet flexibility and adaptability of *P. gracilis* in the Salish Sea.

22-3 Johnson, EH; Paleontological Research Institution; *ehj32@cornell.edu*
Fight or flight: tradeoffs between mechanical and behavioral defenses in bivalve shell shape
Bivalve shells serve as mechanical armor and enable behaviors such as swimming and burrowing to escape predators. Thus, shell shape plays a critical role in a bivalve's ability to defend against attacks from predators like shell-crushers. The shapes of bivalve shells converge on a select few morphologies which correlate with life mode and motility. Additionally, shell shape is believed to be related to shell strength. Here, mathematical modeling and 3D printing were used to analyze the protective function of different shell shapes against vertebrate shell-crushing predators. Considering the life modes different shell shapes permit and

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analyzing their strength in bulk compression provides insight to evolutionary and ecological tradeoffs with respect to mechanical and behavioral defenses. These empirical tests are the first of their kind to isolate the influence of bivalve shell shape on strength and quantitatively demonstrate that shell strength is derived from multiple shape parameters. This theoretical study demonstrates results consistent with examples of shell shapes which allow escape behaviors being mechanically weaker than those which do not. Additionally, shell elongation from the umbo, a metric often overlooked, is shown to have significant effects on shell strength.

11-5 Johnson, LE*; Ivanov, BM; Johnson, MA; Trinity University, Trinity University ; *ljohnso6@trinity.edu*

Does testosterone facilitate dynamic relationships in Anolis lizard behavior, morphology, and physiology?

Testosterone (T) influences a wide variety of sexual and social behaviors, but the extent to which variation in muscle physiology underlies these behaviors is not clear. We investigated the effects of T on the morphology, physiology, and behavioral use of two muscles in green anole (*Anolis carolinensis*) and brown anole (*A. sagrei*) lizards. We examined the ceratohyoid, the muscle that moves the throat fan called the dewlap in social display, and the retractor penis magnus (RPM), a muscle that moves the hemipenes during copulation. We assigned males of each species to one of three treatment groups: high T males were gonadectomized and received a T implant; low T males were gonadectomized and received a blank implant; and control males underwent sham surgery, where their testes were left intact and they received a blank implant. Before surgery, males assigned to these groups did not differ in morphology or behavior, yet six weeks after hormone manipulation, high T males displayed their dewlap more frequently than low T males in both species. However, T affected dewlap size differently between the two species, with T exposure increasing dewlap size in green anoles but having no clear effect on brown anole dewlaps. We are currently measuring the sizes of the CH and RPM, the number and size of their muscle fibers, and androgen receptor expression in myonuclei. The results of this study will help us understand how T

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facilitates dynamic changes in muscles and the behaviors they support.

111-1 Johnson, SL; Heubel, BP; Bredesen, CA; Long, A; Schilling, TF; Le Pabic, P*; University of North Carolina Wilmington, Wilmington, NC, University of Delaware, Newark, DE, University of California Irvine, Irvine, CA; *lepabicp@uncw.edu*

Defining regulators of endochondral growth in cichlid skull evolution

What developmental mechanisms underlie the diversification of skeletal proportions in vertebrates? In tetrapods, variation in long-bone length underlies a great diversity of limb morphologies, and this primarily results from modulation in the degree of cell enlargement at the hypertrophic zone of growth plates. We explore the developmental basis of skull morphology evolution in two closely related species of cichlid fishes from Lake Malawi: *Copadichromis azureus* (CA) and *Dimidiochromis compressiceps* (DC). Our results demonstrate that changes in endochondral growth zone activity underlie major morphological differences that have evolved between CA and DC, yet the cellular mechanisms driving these changes are unlike those reported for tetrapod limb growth plates. Cells proliferate and deposit extra-cellular matrix in cichlid growth zones, yet surprisingly chondrocytes shrink as they mature through the hypertrophic zone in both species. Instead, differences in cell number in proliferating zones correlate with growth velocity, and we find that differences in proliferative zone size arise during embryonic development, before the appearance of distinct skeletal morphologies. Lastly, we find that one large-effect QTL mediates the difference in proliferative zone size between DC and CA.

19-11 Johnson, JR*; Piland, NC; University of California, Davis, University of Chicago; *jcbjohnson@ucdavis.edu*

Can you sing that again? Assessing wide-scale vocal adjustment in urban songbirds

Songbirds rely heavily on vocalizations for communication, territory defense, reproduction and in other contexts. Anthropogenic noise may be a widespread cause of vocal adjustment

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in urban songbirds. Therefore, understanding the effects of chronic noise on avian acoustic signaling systems is a key part of understanding the adaptability of these organisms to human-altered environments. While many case studies have focused on vocal adjustment in individual species, few comparative multispecies studies exist. This study looked for broad patterns of vocal adjustment by comparing the vocalizations of thirty-eight songbird species in both urban and rural environments. We quantified individual vocalization rates in recordings obtained from the Macaulay Library, Xeno Canto, and eBird, taking samples from seven countries and ten cities worldwide. We then used a matched-sample analysis to look for trends across all species assessed. Our results show that individual songbirds in urban environments signal significantly more frequently than their rural counterparts, supporting the hypothesis that many songbird species are changing their vocalizations in a similar manner. This difference in signaling rates may be attributable to vocal adaptation in the face of a noisy environment, stress due to noise-induced hypervigilance, or some combination of the two. Further research is required to isolate the source of the behavioral discrepancy between urban and rural songbirds, but this study nonetheless suggests that vocal adjustment in songbirds is prevalent on a global, multispecies scale.

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Field studies of lizard copulation: from physiological mechanisms of mating to behavioral correlates of paternity

Animal mating can be understood as a sequence of events that begins with individuals encountering one another and ends with the production of offspring. Behavioral descriptions of animal mating systems characterize early elements of this sequence, and genetic descriptions use offspring paternity to characterize the final outcome, with mechanisms of copulation and fertilization comprising intermediate steps. However, behavioral and genetic descriptions of mating systems are often inconsistent with one another, and the

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framework of territoriality may contribute to this inconsistency. The lizard *Anolis cristatellus* has long been described as territorial, and here we use behavioral and genetic data from this species to test hypotheses predicted by the territorial framework. We find that 26% of offspring are sired by males whose home ranges do not overlap those of the mother, a substantial departure from expectations under territoriality. We also find that proximity in space and time and male body size, but not display behavior, are significant correlates of whether a male sires a particular female's offspring and how many offspring he sires. Our results indicate sexual selection on male body size, and suggest that more nuanced approaches are necessary to understand the role of male display in these lizards' mating behavior.

45-3 Johnson, MG*; Glass, JR; Harrison, JF; Arizona State University, Tempe; *mgjohn12@asu.edu*

Thermoregulatory tactics and water balance of flying metander Centris caesalpiniae males

It is advantageous for flying insects to be functional across a range of temperatures when competing for mates; breadth of performance can arise from broad tolerance or thermoregulation. Tactics of flying insects typically include moving hot hemolymph from the thorax to cooler body segments, evaporative water loss, and changes in metabolic heat production. For dimorphic *Centris caesalpiniae* male bees, large morphs (metanders) dig for females at ground-level, flying infrequently, whereas the small morph hovers and flies. At a mate-aggregation site, air temperature varied from 17 ° C to 37 ° C across and within days; operative temperatures of metanders reached 50 ° C on the ground when mating activity ceased, suggesting that high temperatures and radiation constrain the mating period, and that *C. caesalpiniae*'s upper thermal tolerance is high, but not exceptional. These bees exhibited modest thermoregulation of thorax and head temperatures, with segment temperatures increasing 0.5-0.6 ° C per ° C air temperature both on the ground and in flight. During flight, evaporative water loss and heat movement to the abdomen contributed to thermoregulation. On the ground, bees moved hemolymph to the head. These results suggest bees thermoregulate the thorax to improve flight performance. Metabolic water production was about half of water loss rates and

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metanders lose about 17% of their body water per hour during flight. No one has observed metanders feeding or drinking; several hours of flight would presumably cause a lethal loss of body water. While we currently lack information on the duration of activity of individuals, it is possible that thermoregulatory water loss may constrain the activity of metanders. Supported by 2019-2020 Fulbright Student Program and USDA 2017-68004-26322.

59-10 Johnstone, JB*; Rahman, MS; Texas A & M Corpus Christi, University of Texas Rio Grande Valley; *jjohnstone1@islander.tamucc.edu*

Effects of rising temperatures on physiological functions, protein expression, and cell death in an Echinoid species

Increasing surface sea temperatures are increasingly impacting marine and coastal environments. Bioindicator species can be used to discern broad patterns about global climate changes that are applicable to many taxa. In addition to being a bioindicator species, Atlantic sea urchins (add scientific name) also have relatively simple systems with few internal mechanisms that could confound observed responses. We tested the effect of temperature on reproductive functions, nitrotyrosine protein expression, heat shock protein expression, and coelomic fluid (CF) conditions in Atlantic sea urchin. Ten sea urchins were placed in each of six 20-gallon aquariums set to 32oC, 28oC, or 24oC (control) under controlled laboratory conditions for a 7-day period. Male and female sea urchins exposed to the high temperatures had lower gonadal growth compared to those exposed to the control temperature. The percentage of mature ova was significantly lower at high temperatures compared to the control temperature, indicating impaired ovarian functions at elevated temperatures. There was an inverse relationship between sperm production and temperature. Sea urchin exposed to high temperatures showed an increase in nytrotyrosine expression and heat shock protein expression in ova, follicles, and sperm, as well as increased cellular apoptosis and decreased CF pH compared to controls. These results suggest that elevated water temperature decline/acidify CF pH which might be involved in the impairment of reproductive functions and cellular apoptosis in Atlantic sea urchin.

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97-8 Jones, AE*; Conway, KW; Webb, JW; University of Rhode Island, Kingston, RI, Texas A&M University, College Station, TX; *aubree_jones@uri.edu*

The best of both worlds: regional specialization in the mechanosensory system of the silverjaw minnow, Ericymba buccata

Species that have atypical morphologies present unique opportunities to deepen our understanding of adaptive evolution. The mechanosensory lateral line system (LL) of bony fishes is defined by five LL canal phenotypes, including narrow and widened canals, which typically occur in different species. One of the few species to have both narrow and widened canals in the same individual is the silverjaw minnow, *Ericymba buccata*. The canals are regionally specialized, with widened canals below the eye and on the lower jaw (infraorbital, mandibular canals) and narrow canals (supraorbital, temporal, supratemporal canals) on the dorsal side the head. Widened canals play a critical role in benthic nocturnal feeding in other species and are hypothesized to mediate this behavior in *E. buccata*. Here we describe the morphology of the cranial LL canals (canal and neuromast receptor organ size and shape) and give the first report of superficial neuromast distribution and morphology using histology, SEM, and fluorescent staining of neuromasts. The widened canal neuromasts are three times the diameter of the narrow canal neuromasts (mean=12.9 vs. 3.4 mm, respectively), but both types of canal neuromasts are similar in shape (length:width=2.5 vs. 2.3, respectively). Numerous superficial neuromasts and external taste buds have overlapping distributions on the skin, which has not been widely reported among fishes. This study is increasing our understanding of the development and evolution of specialized phenotypes in the LL system and of regional specialization as a trend in adaptive evolution. Funding: SICB FGST and NSF Graduate Research Fellowship (AEJ), TAMU Agrilife Research to KWC, George and Barbara Young Chair in Biology (JFW).

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Glucocorticoids correlate with and predict social status in the

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cooperatively breeding lance-tailed manakin (Chiroxiphia lanceolata)

Cooperation is a feature of many social species and occurs when one organism increases the potential fitness of another at an apparent cost to their own. Many have saught to explain the ultimate mechanisms of the evolution of cooperative behaviors, but less is known about the proximate mechanisms that drive cooperation. We assessed the potential link between stress physiology and social behavior in a tropical bird that displays variation in social status, which plays a key role in cooperative courtship. Many lance-tailed manakin males form partnerships to perform complex displays for potential mats. These partnerships are dominated by an alpha male, while subordinate beta males help to attract females but rarely have the opportunity to breed. While most males participate in cooperative displays, many individuals do not cooperate as an alpha or beta, termed ‘marginal males’. Glucocorticoids, steroid hormones associated with the physiological stress response, often correlate with behavioral phenotypes and have been associated with dominant and subordinate behaviors in other species. We found that stress-induced and baseline levels of glucocorticoids differed among alphas, betas, and marginal males. Further, stress-induced concentrations of glucocorticoids predicted future social trajectories. Juvenile males with high stress-induced measures of glucocorticoids were more likely to attain beta or alpha status within the first 2 years of becoming a reproductively mature male. These finding suggest that glucocorticoids play an important role in social status and the formation of male-male alliances. Higher levels of baseline and stress-induced glucocorticoids may reflect the energy demands associated with courting females. However, the predictive nature of stress-induced glucocorticoids suggests the link reflects more than immediate metabolic demands.

BSP-6-7 Jongsma, GFM*; Barve, N; Allen, JM; Blackburn, DC; Florida Museum of Natural History, University of Florida, Gainesville, FL, Department of Biology, University of Nevada Reno, Reno, NV; *gregor.jongsma@gmail.com*

Historical forest stability shapes contemporary patterns of afrobatrachian frog diversity in central africa

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The latitudinal gradient hypothesis describes the observation that diversity increases as you travel from the poles towards the equator. Even at the equator diversity is not equally distributed. Understanding what spatial and temporal features best explain these local differences can help elucidate what processes drive and maintain biodiversity. The refuge hypothesis predicts that fluctuations in climate drove cyclical isolation of forest refugia, leading to isolation of populations and allopatric speciation. Historical refugia provide an enticing scenario to explain the unequal distribution of species in the tropics. To estimate centers of forest stability (refugia), we hindcasted 20 forest-obligate frog species back 2.5 million years. Stability was estimated based on how many species were present in a cell for >90% of the time slices. To explore how forest stability has shaped contemporary diversity we focused on Afrobatrachian frogs in the Lower Guinean Forests (LGF). Afrobatrachia is a highly diverse group and represents ~50% of frog species in the LGF. In total, 124 species out of the 128 Afrobatrachia known in the region were included. We used the phylogeny from Portik et al. (2019) to estimate phylogenetic diversity and phylogenetic endemism. Using linear regression models, we show that historical stability positively explains heightened Afrobatrachia PD and PE in the LGF. Directly testing the influence of historical habitat stability can help elucidate evolutionary processes, not only at the species-level, as demonstrated here but also in population genetics and functional diversity research.

94-4 Jordan, KA*; Yarger, AM; Fox, JL; Case Western Reserve University; *kaj67@case.edu*

Halteres increase takeoff speed in calyptratae

Dipteran insects (flies) possess mechanosensory organs called halteres. Halteres are used during flight to take in information about how their body is rotating. Although research has shown that halteres are essential for steady flight, very little is known about their role in takeoff behavior. However, it has been documented that some groups of flies oscillate their halteres during pre-flight behavior (walking). Most notably, the Calyptratae, a large and diverse clade including some very successful flies like blowflies and houseflies, all move their

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halteres when they walk. This suggests that these flies may use the sensory information generated by the halteres in behaviors other than free-flight. In this research, our goal was to determine how halteres impact takeoff in various species and whether haltere use may help explain differences in takeoff behaviors between those species. To accomplish this, we recorded spontaneous and escape takeoffs in several species of wild-caught and lab-reared flies. After filming the behavior of intact animals, we gently removed the halteres, allowed the flies to recover, and stimulated them to perform escape takeoffs. We found that intact flies of the Calyptratae clade performed takeoffs that were significantly faster than most other fly groups, and that removing the halteres made their takeoffs slower. Removing the halteres of flies outside the Calyptratae clade had no effect on the speed of the takeoff. Taken together, our results suggest that the Calyptratae flies have expanded the use of their halteres to enhance takeoff as well as to stabilize flight.

30-4 Jorgensen, MA*; Hews, DK; Indiana State University, IN; *mjorgensen@sycamores.indstate.edu*

Hair cortisol for non-invasive health evaluation in the big brown bat, Eptesicus fuscus

Glucocorticoid (GC) hormones, provide basic information on endocrine activity as a function of interactions with their environment. When faced with short-term stressors, GCs elevate to mobilize glucose and coordinate activity of other metabolic processes as an adaptive response to the stressor. A multi-year project with the Missouri Department of Conservation aims to evaluate health and population responses of bats by comparing them on sites specifically managed for the endangered Indiana Bat, to those on reference sites not so managed. Our health goal is to obtain longer-term measures of cortisol, the main GC in microbats, from hair samples, and compare young-of-the-year bats across sites to give insight to potential differences in stress due to management practices. To refine our methods we focused on samples from Big Brown Bat, Eptesicus fuscus (EPFU), a relatively well-studied North American species. To start, we first pooled male EPFU hair samples from adult males, prepared the hair for hormone extraction by performing a series of ethanol washes, evaporating,

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and homogenizing. We then extracted known weights of hair in known volumes of 100% methanol, and used methods from Wada et al. (2007) to optimize use of enzyme immunoassay kits to measure cortisol. Then, we assayed selected EPFU hair samples across a range of sex, reproductive state, and ages (adult, juvenile) to explore the range of values in hair cortisol. Non-reproductive juvenile males had the highest mean cortisol levels (0.36 ng cortisol/mg hair) across sex, age and reproductive classes. Among all females, lactating females had the highest mean cortisol levels (0.22 ng/mg). Excluding pregnant females, hair cortisol did not vary with body mass, in either sex. Currently we are evaluating effects of sample time in freezer and of body location sampled on cortisol estimates.

14-2 Joyce, M*; Wilshin, S; Qian, F; Spence, A; Temple University, Royal Veterinary College, University of Southern California; *michelle.joyce@temple.edu*

Gait control for obstacle negotiation in canines

Understanding the biomechanics of how animals overcome complex environments has significant implications in biology and engineering. These include obstacle negotiation, neural and mechanical control, and applications in robotics as biological systems remain superior in this domain. Here we examine how flexibly controlled quadrupedal obstacle negotiation is constrained by the structure of typical animal gaits and the environment. Past research has found that as a quadrupedal robot moves over a regular array of domed obstacles, gait type and obstacle contact result in stable locomotion with a systematic change in direction. As dogs have additional flexibility and must consider tradeoffs between desired gait, navigation, and energy expenditure, we hypothesized that in a similar array, dogs would change gait parameters including duty factor, limb phase, stride length, as well as direction of locomotion. To begin investigating the effect of space between obstacles, we quantified the natural step length of eleven dogs, and used this to normalize spacing for body size. Spacing was also increased and decreased by 20% from that value. For one adaptation, we hypothesized that with longer spacing, dogs would spend less time with their paws on the ground, thus having a lower duty factor. Preliminary results do indicate a negative relationship between spacing size and duty factor. Using a

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generalized linear mixed effects model, the effect size was -1.86, with standard error 0.14, $p<0.01$, for n=11 dogs. Continuing analysis of additional parameters will further investigate a dog's ability to cope with obstacle fields. Adapting these strategies in robotic systems will allow for greater flexibility in cluttered environments by employing more stable and economical locomotion.

51-7 Judson, JM*; Bronikowski, AM; Iowa State University; *jjudson@iastate.edu*

The genomics of life-history: genomic variation between life-history ecotypes of the western terrestrial garter snake (Thamnophis elegans)

The evolutionary origins and adaptive significance of life-history variation among organisms have been long-standing questions since the inception of the field. We present data on the genomic underpinnings of life-history variation in populations of garter snakes characterized by two life-history ecotypes. The first, which inhabits mountain meadows of Lassen County, California exhibits a "slow-paced" life-history ecotype (M-slow) of slow growth, late maturation, small reproductive effort per bout, and long lifespan. The contrasting "fast-paced" life-history ecotype is found in lakeshore habitats (L-fast). Laboratory common garden and reciprocal transplant experiments have revealed both genetic and environment contributions to these ecotypes, which are further characterized by physiological differences in stress responses, differences in coloration, scale counts, and diet. Here we address the genomic underpinnings of this variation. We assessed both population structure and genomic variation between the two life-history ecotypes using whole-genome resequencing. Preliminary principal component analyses of >10 million SNPs in four populations representing both ecotypes (60 individuals) suggest that 14% of the variation in the genomic dataset is explained by differentiation among the ecotypes, and there is additional variation among populations consistent with isolation by distance. We aim to assess the genomic regions under selection that contribute to life-history variation, which will further our understanding of how complex traits such as lifespan can diverge rapidly and be maintained in systems with low levels of gene flow.

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11-8 Juntti, SA*; Li, C-Y; University of Maryland, College Park; *sjuntti@umd.edu*

A dual role for prostaglandin F signaling in hormonal and pheromonal signaling in cichlid fish

Mating relies on detection of cues that indicate species, sex, and status of potential partners. Integration of this information is biased by the reproductive status of the receiver, but the mechanism is unclear. Progestin and prostaglandin F2-alpha (PGF) have been previously implicated as key signals that convey fertility status to the brain in a variety of vertebrate species, and their serum levels rise before fish mate. We take advantage of reproductive behavior in the cichlid fish Astatotilapia burtoni, which exhibits quantifiable spawning routines and is genetically tractable with CRISPR/Cas and Tol2 transgenesis. We find that PGF injection rapidly triggers naturalistic spawning behavior. CRISPR mutagenesis of either the progestin receptor (Pgr) or the PGF receptor (Ptgfr) results in a complete abolition of female spawning behaviors. These and other results lead us to a model in which Pgr signaling drives transcription of Ptgfr and increased sensitivity to PGF. PGF in turn activates Ptgfr in key regions of the brain to rapidly drive spawning behavior after ovulation. We infer that PGF-sensitive cells in the female brain form an integral component of a neural circuit for mating. Furthermore, while cichlids are insensitive to PGF released into the environment, it initiates a pheromonal signaling from females, attracting males. I will discuss the nature of this pheromone and its perception. Thus, PGF initiates hormonal and pheromonal signaling that synchronizes behavior of males and females.

28-6 Kahn, AS*; Daniels, J; Lord, JP; Katija, K; Barry, JP; Moss Landing Marine Laboratories, CA & San Jose State University, CA, MBARI, Moss Landing, CA, Moravian College, Bethlehem, PA; *akahn@mlml.calstate.edu*

Factors affecting respiration and water processing by deep-sea sponges

Benthic communities in the deep sea rely on food imported from elsewhere because there is no local primary production in the

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absence of light. Instead, the required nutrients arrive either by sinking from the photic zone or via lateral currents. Food is therefore often limiting in the deep ocean, yet in some locations, dense communities manage to flourish. Sur Ridge is a deep submarine ridge (800-1700 m depth) off the coast of Big Sur, California that supports dense gardens of corals and sponges. The impact of these organisms as foundation species is clear, but what affects their distributions is not fully resolved. To investigate this, we focused on sponges and studied pumping activity and metabolic rate at different locations of Sur Ridge. We measured *in situ* respiration using optical oxygen sensors. Activity levels, as pumping rates, were measured using a deep-sea particle imaging velocimetry system (DeepPIV) deployed by remotely operated vehicle. Measurements were performed across a range of species growing under different ambient oxygen and depth regimes. Respiration varied between species but bulk oxygen removal was similar across depths. DeepPIV revealed that the glass sponges of Sur Ridge pump many times their own body volume of water each day, with pumping rates dependent on osculum size. Pumping rates of some species, such as those of the subfamily Acanthascinae, were rapid whereas excurrent flow rates from others, such as *Staurocalyptus* sp., were much slower. These species do co-occur, but each dominates in a different part of Sur Ridge, suggesting niche partitioning and species-dependent adaptation to different water conditions.

68-10 Kahrl, AF; Department of Zoology/Ethology, Stockholm University, Stockholm, Sweden; *ariel.kahrl@zoologi.su.se*

Rapid evolution of sperm midpiece size across the animal tree of life

Sperm size is one of the most diverse traits across the animal tree of life, but even more variable perhaps is the shape of the cell. In many lineages, the cell is composed of a head (which contains the nuclear material), a midpiece (which contains the mitochondria), and a flagellum (which propels the cell). As each part of the sperm has a unique function, it seems likely that each component may follow a different evolutionary trajectory. However, genetic correlations between these cellular components could result in correlated shifts in size of multiple parts of the cell. I tested these hypotheses by collecting sperm morphological data for

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1194 vertebrate species. For each vertebrate class I measured the rate of evolution of the sperm head, midpiece, and flagellum and located evolutionary shifts in size for each of these components on the tree. I found that across animals the sperm midpiece evolves faster than both the head and flagellum, indicating strong selection for sperm energetics. Additionally, head length evolves slowly in almost all lineages, suggesting that its diversification may constrained by functional limitations. I found that branches which contained an evolutionary shift in the size of one sperm component often contained shifts in the size of other parts of the cell. This suggests that genetic correlations between the sperm components cause parts of the cell to have a concerted response to selection. These results suggest that while postcopulatory selection on specific components of sperm may result in faster rates of evolution, genetic correlations within the cell can either constrain or promote faster evolution of the other components of the sperm cell.

80-11 Kallal, RJ*; Wood, HM; National Museum of Natural History, Smithsonian Institution, Washington, DC; *kallal.research@gmail.com*
Strike kinematics of the araneoid trap jaw spider Pararchaea alba
In various animal lineages, muscles are supplemented by latches and springs to store energy. When released, power is achieved nearly instantaneously exceeding what muscles alone typically produce. An example of this is the trap jaw mechanism found in arthropods in which the mouth parts are brought together in a pincer at extremely high speeds. In spiders, the best known and only well-documented such group is the trap jaw spiders of the family Mecysmaucheniidae (Palpimanoidea). However, a distantly related taxon within the orb-weaving spiders, Pararchaeinae (Malkaridae, Araneoidea), exhibits a very similar morphology and behaviors. Using micro-computed tomography and high speed videography, we characterize the strike kinematics and related morphology of *Pararchaea alba*. Our results show *P. alba* strike speeds are within the observed range of the slower mecysmaucheniid species but do not attain the power amplified speeds of the fastest strikers in that family. We speculate this intermediate speed stems from the presence of some - but not all - observed characteristics associated with high speed strikes in other such lineages, allowing versatility in their

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chelicerae, which are multi-purpose structures. Finally, the preservation of a specimen in the latched position allowed comparison of the muscles in that state versus the more common resting state, and we suggest an alternative mechanism for cheliceral function in these odd spiders.

93-3 Kamska, V*; Contreras, FB; Daley, M; Badri-Spröwitz, A; MPI for Intelligent Systems, Stuttgart, University of California, Irvine; *kamska@is.mpg.de*

Associating functional morphology of the lumbosacral organ and locomotion modalities in avians

Birds live in almost every environment; they fly, run, swim, dive, and climb. Recently, it has been suggested that an additional, putative mechanosensing organ, the lumbosacral (LS) 'organ,' might contribute to their outstanding locomotor ability. We assume that the LS structure/organ's functional morphology results from an evolutionary adaptation and correlates with the locomotion modality in avians. The avian LS region shows several unique adaptations among vertebrates; a glycogen body wedged between spinal cord hemispheres, a spinal cord, which is ventrally supported by a denticulate ligaments network. Accessory lobes with potentially mechanoreceptive capabilities protrude into the canal from the spinal cord margins and close to the denticulate ligaments. The LS canal expands near the glycogen body, and the canal's segments are fused into transverse semicircular grooves at the dorsal side (Kamska et al., in review). We suspect that each locomotion modality requires its own, finely tuned sensor adaptation. Although not yet proven, intraspinal (!) sensor information from accessory lobes would provide the necessarily rapid and sensitive locomotion feedback. Depending on the locomotion mode's sensory needs, the LS canal and its soft tissue functional morphology would differ, with specific physical attributes pronounced over others. We started collecting data from ground-dwelling, land-fowl, and waterfowl birds. We chose a set of functional morphological landmarks based on the 3D segmentation of the LS canal endocasts and related structures. So far, we have found and characterized large differences between birds with different locomotion habits. We are in the process of establishing the correlation between their locomotion mode and functional morphology.

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4-7 Kane, SA; Bien, T; Contreras-Orendain, L; Ochs, MF; Hsieh, ST*; Haverford College, The College of New Jersey, Temple University; *sthsieh@temple.edu*

Spotted lanternfly nymphs stick the landing using multiple self-righting behaviors

Many climbing arthropods and arboreal vertebrates use aerial self-righting to mitigate the risks associated with falling. Landing upright can maximize survival, even for animals small enough to avoid impact damage, by minimizing the cost of terrestrial self-righting and facilitating predator evasion. Spotted lanternflies (*Lycorma delicatula*) (SLFs) are invasive insect pests that frequently fall from host plants for predator avoidance and in response to abiotic factors (e.g., wind). We studied whether falling immature SLFs land upright more often than expected by chance, and, if so, whether they do so via active or passive mechanisms. Dropping tests of live 2nd through 4th instar nymphs falling 20 cm from a variety of different initial orientations revealed that during and after release, SLFs frequently reorient and tumble, suggesting that initial orientation alone does not determine falling behavior. Live SLFs landed upright in more trials (44-55%) than did dead SLFs (7-38%), with differences being highly statistically significant. High speed video showed that falling live SLFs adopt a stereotyped falling posture similar to that used by falling aphids, ants, geckos, frogs, and skydivers. Unexpectedly, we also found that significantly more SLFs reoriented to upright from other initial landing positions by a combination of bouncing and levering themselves upright using one or more legs holding onto the substrate, indicating the important role post-impact self-righting plays in determining final orientation. By studying SLFs filmed falling onto both hard, flat surfaces and compliant leaves, we confirmed that these insects can use multiple tactics to land upright on host plants.

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57-9 Kane, SA; Bien, T*; Hsieh, ST; Haverford College, Temple University; *samador@haverford.edu*

Field experiments uncover variable anti-predator behaviors used by spotted lanternfly nymphs

Spotted lanternflies (*Lycorma delicatula*) (SLFs) are univoltine planthoppers newly invasive to the northeast United States. While several studies have examined the antipredator behavior of winged adults, little is known about how wingless nymphs respond to threats. This study used field experiments to determine whether a variety of different simulated predator visual stimuli (i.e., bare/gloved hands, forceps, bird and insect dummies), and a tactile stimulus (warm, humid breath) elicit antipredator responses in SLF nymphs. We also wished to explore whether the dropping and jumping avoidance behaviors found in other insects and small arboreal vertebrates are used by this species. Because these strategies are thought to enhance short-term survival but risk loss of the host plant, we researched the SLF's preferred host, Ailanthus altissimus, to understand how its densely-stacked foliage might provide potential landing sites within the original plant. While first to third instar nymphs are black with white spots, the much larger fourth instar nymphs have conspicuous red patches that likely serve as an aposematic signal of unpalatability, suggesting the hypothesis that, like pea aphids, SLFs also might employ different defense mechanisms at different life stages. Second and third instar nymphs were found to be most responsive to the insect dummies as a visual stimulus, moving away or hiding in 66% and jumping/dropping in 34% of trials, and to respond to warm, humid breath by jumping/dropping in 65% of trials (a behavior previously proposed to reduce risk of incidental ingestion by herbivores). By contrast, except for shortly after emergence, the fourth instar nymphs ignored simulated predator attacks, though they readily jumped or dropped to evade humans.

S8-9 Kang, V*; Federle, W; Department of Zoology, University of Cambridge, UK; *kwk22@cam.ac.uk*

It's a trap! How sticky fluids help carnivorous plants catch insect prey

Many plants secrete sticky fluids that fulfil important biological functions. Climbing plants, such as the English ivy, use adhesive secretions to cling to vertical surfaces, while orchid flowers courier their pollen to other flowers by gluing their pollinaria to bees. One of the most striking and specialised uses of sticky secretions can be found in carnivorous plants. These plants live in

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nutrient-poor soils and supplement their nutrition by catching and digesting insects. Many carnivorous plants, including sundew (*Drosera*) and several pitcher plant species (*Nepenthes*), secrete sticky fluids to aid in prey capture and retention. Despite the important biological function of these adhesive secretions, we have a limited understanding of the chemical and physical properties. In addition, we lack insight into the forces experienced by insects trying to escape from the sticky secretion. In this study, we use the sticky pitcher fluid from *N. rafflesiana* to investigate the underlying mechanisms of their effective prey capture. We show that a greater proportion of ants sink in pitcher fluid than in water, likely based on the combined effect of reduced surface tension and delayed dewetting of the fluid from insect cuticle. We also demonstrate that retracting insects from sticky pitcher fluid required significantly more work than retracting them from water, which can further impede their escape. Detailed chemical characterisation of the fluid revealed that it is made up of a large acidic polysaccharide. This polysaccharide is also the principal component of the sticky capture fluid of sundew plants, a distant relative to Nepenthes pitcher plants, raising interesting questions about the evolutionary origins of this shared trait.

S10-2 Kanso, E; University of Southern California; *kanso@usc.edu*
Transitions in cilia coordination
Multitudes of motile cilia covering epithelial surfaces in the mammalian airways, fallopian tubes, and the brain synchronize their beat to enable efficient fluid transport. The nature of the mechanisms leading to (large scale) ciliary coordination remains unclear. I will review our understanding of this process based on physics-based mathematical models where hydrodynamic forces between near beating cilia are sufficient to lead to cilia coordination. Further, I will demonstrate that it is possible to reach, and transition between,multiple synchronization states by varying the intrinsic activity of the cilium and the strength of hydrodynamic coupling between neighboring cilia. I will conclude by commenting on the implications of these findings to our understanding of cilia coordination in epithelial tissues under healthy and diseased conditions as well as in unicellular organisms where transitions

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between distinct modes of cilia coordination are crucial for the cell behavior and survival.

S6-12 Kanwal, J; Davila, K; Frazer, R; Givens, M; Castro Perez, DL; Turner, G; Coddington, E; Wasserman, S*; California Institute of Technology, Willamette University, Wellesley College, Wellesley College; *swasserm@wellesley.edu*

Internal state: bidirectional brain-body axes of communication

The brain and the body must communicate with each other in order to facilitate behaviors that are adaptive to spatiotemporally fluctuating internal physiology and external environments. Here, we identify and share three frameworks that provide distinct perspectives and approaches for exploring how the brain and body work together to communicate internal state. Each approach reveals key components, interactions, and networks that define internal state across different spatial and temporal scales. Whereas a top-down perspective provides a framework with a focus on how internal state is represented in brain structure and function, and how this information is used to modify signals from the brain to regulate and instruct the body, a bottom-up perspective focuses on how internal state is represented in the body, and how this information is used to send signals and coordinate responses from the brain and across different organs. Finally, a bidirectional perspective focuses on how internal state is simultaneously represented in and communicated between the brain and body in order to instruct and influence behavior and whole body function. We will primarily focus on the third framework by exploring studies that reveal the importance of bidirectional brain-body communication on tuning sensory perception to drive adaptive behavior across invertebrate and vertebrate organisms.

70-2 Karakas, F*; Maas, AE; Murphy, DW; University of South Florida, Bermuda Institute of Ocean Sciences; *ferhat@usf.edu*

Shell shape and size defines the swimming and sinking characteristics of pelagic snails

The swimming and sinking behavior of pelagic snails is not well known but is important in their ecology and predator-prey interactions. We used a low magnification, high speed

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stereophotogrammetry system to study the swimming and sinking kinematics of nine warm water pelagic snail species (seven thecosomes, one gymnosome, and one heteropod). As different thecosomatous pteropod species may have coiled, elongated, or globular shell morphologies, we focused on how the shell shape, body geometry, and body size affect their swimming behavior from a fluid mechanics perspective. While different large scale swimming patterns were observed, all species exhibited small scale sawtooth swimming trajectories caused by reciprocal appendage flapping. Thecosome swimming and sinking behavior corresponded strongly with shell morphology, with the tiny coiled shell pteropods swimming and sinking the slowest, the large globular shelled pteropods swimming and sinking the fastest, and the medium-sized elongated shell pteropods swimming and sinking at intermediate speeds. However, the coiled shell species had the highest normalized swimming and sinking speeds, reaching swimming speeds of up to 45 body lengths s^{-1}. The sinking trajectories of the coiled and elongated shell pteropods were nearly vertical, but globular shell pteropods use their hydrofoil-like shell to glide downwards at approximately 20° from the vertical, thus retarding their sinking rate. The swimming Reynolds number (Re) increased an order of magnitude between consecutive shell categories, suggesting that more recent lineages increased in size and altered shell morphology to access greater lift-to-drag ratios available at higher Re.

BSP-10-9 Karan, EA*; Schwartz, ST; Perillo, M; Alfaro, ME; University of California, Los Angeles ; *ekaran@g.ucla.edu*

It's not just a phase: evolutionary and functional consequences of sexually dimorphic color pattern diversity in labrid fishes

Sexual color dimorphism is largely attributed to sexual selection, where different sexes will broadcast distinct displays to conspecifics to convey information such as mating availability and fitness for reproduction. This is balanced by the effects of natural selection, where colors that allow an organism to mitigate conspicuousness to potential predators may also contribute to fitness. Colors themselves contribute to conspicuousness, but so can overall pattern through the juxtaposition of adjacent or other co-occurring colors. Among species that exhibit sexual color dimorphism, disparity in color pattern geometry contributes to

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differences in relative conspicuousness towards both predators and conspecifics among sexes. We quantify color pattern geometry and complexity across males and females of dichromatic and non-dichromatic species of wrasses (Labridae) using *charisma*, a novel color classification method that automatically detects the number and proportions of color classes on each individual to best capture overall pattern diversity. While previous work has examined the evolution of color dimorphism in terms of the presence or absence of discrete colors across labrids, the evolution of the relative proportion and distribution of colors that comprise patterns among sexually dichromatic species has not been previously evaluated. We also use visual models and phylogenetic comparative methods to test how males and females diverge from one another in terms of statistics that capture color pattern geometry. We demonstrate that not only color composition, but also relative proportion and orientation of colors in patterns have important implications for different life histories among sexes of wrasses.

15-2 Karimjee, K*; Olsen, E; Piercy, RJ; Daley, M; Royal Veterinary College, London, Swedish University of Agricultural Sciences, Uppsala, University of California, Irvine; *kkarimjee@rvc.ac.uk*
Quantifying canine activity using collar-based accelerometers: a cut-point free approach
Objective assessment of activity through accelerometry can provide valuable insights into dog health and welfare. Commonly used metrics for activity monitoring involve grouping of data into intensity categories (e.g. light, moderate) based on acceleration cut-points and reporting the time spent in each category. However, a lack of consistency in selected cut-points and transparency in their derivation, makes it difficult to compare studies. This approach also limits the information resolution about intensity of activity within the cut-point categories. We present a case study for an alternative metric, first presented in humans, for use in dogs: the acceleration threshold (g) above which the animal's X most active minutes are accumulated (MX_{ACC}) over a 24-hour time period. We report $M2_{ACC}$, $M30_{ACC}$ and $M60_{ACC}$ data from a colony of healthy laboratory beagles aged 2-18 months old. Axivity-AX3 accelerometers are attached to the ventral region of each dog's collar. Data are recorded at 200 Hz for 24 hours and the dogs

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follow their normal daily routine. Acceleration vector magnitude is calculated and $M2_{ACC}$, $M30_{ACC}$ and $M60_{ACC}$ are computed. Using labelled accelerometer data, we characterise the range of acceleration outputs exhibited for a variety of relevant locomotor behaviours (e.g. walk). This enables meaningful interpretation of the MX_{ACC} data to species-specific activities, rather than to generalised intensity of movement. Use of these metrics will further standardise measurement of canine activity, inform development and monitoring adherence of exercise guidelines for dogs and serve as functional outcome measures for research and clinical applications.

12-6 Kasoju, VT; Ford, MP*; Santhanakrishnan, A; Oklahoma State University; *askrish@okstate.edu*

Effects of hinge angle variation on metachronal paddling

Crustaceans such as krill and many other ecologically important marine invertebrates stroke multiple appendages in an oscillatory pattern as a mode of locomotion, known as metachronal swimming. During a metachronal stroke, each swimming appendage (pleopod) is moved with a phase lag relative to its neighboring appendage. Crustacean pleopods are typically jointed, with the bottom portion (endopodite and exopodite) being able to fold up during recovery stroke (posterior-to-anterior motion) to reduce drag, while unfolding during power stroke (anterior-to-posterior motion) to increase thrust. Previous studies have reported on the variation in phase lag (ϕ) and joint angle (β) of each pleopod. Changes in ϕ and in the limits of β could help an animal achieve more thrust or lift generation necessary to achieve horizontal or vertical motion, or hovering. In this study, we investigate the effects of variation in ϕ and β on lift and drag using a two-dimensional computational model with 5 flat-plate paddles, each with a hinge halfway along its length. Modeling was performed in ANSYS Fluent 2019 R3, and the motion of both the top and bottom portions of the paddles was prescribed. Both the stroke amplitude of the upper (root) portion of the appendage (75 degrees) and the stroke frequency (2.5 Hz) were kept constant. We examined the force generation, inter-appendage pressure distributions, and fluid dynamic characteristics of the wake for varying minimum β in the range of 120-180 degrees and ϕ in the range of 0%-30% of cycle time. While keeping ϕ

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constant, varying β from 120-135 degrees showed little to no variation in the vortex wake behind the tail-most paddle after the start of recovery stroke.

66-10 Kasoju, VT*; Santhanakrishnan, A; Oklahoma State University; *askrish@okstate.edu*

Sticky flapper: three-dimensional flapping flight with bristled wings

Thrips and several parasitoid wasps with body lengths under 2 mm, are often observed to possess bristled wings and use wing-wing interaction (clap-and-fling) during free flight. Our previous 2D clap-and-fling studies have shown that bristled wings augment lift-over-drag ratio at Reynolds number (Re) relevant to tiny insect flight (Re=10). However, previous studies using 3D wingbeat kinematics have primarily focused on examining force generation by solid (non-bristled) wings across varying Re. In this study, we aim to evaluate if the aerodynamic benefits of bristled wings are also observed when using 3D wingbeat kinematics. A dynamically scaled robotic model capable of replicating realistic 3D wingbeat kinematics during hovering was developed. We examined the flow structures generated by solid and bristled wings (single wing and wing pair) at Re ranging from 10 to 120 for real insect wing kinematics of thrips and fruit flies. Flow structures generated by the wings and their implications on forces will be discussed.

69-8 Katija, K*; Roberts, PLD; Daniels, J; Henthorn, R; Klimov, D; Ruhl, H; Sherman, AD; Monterey Bay Aquarium Research Institute; *kakani@mbari.org*

EyeRIS (Remote Imaging System): A novel, in situ lightfield imaging system that enables time-resolved three-dimensional visualizations of particles and animals in the deep sea

The deep sea is the largest habitable ecosystem on the planet and remains one of the least explored, and subsequently very little is known about deep sea inhabitants, their behavior, and the limits and drivers for their survival. Ecomechanics, the multidisciplinary research field of the mechanisms that underlie organismal interactions and survival within their environment, has proven largely successful in terrestrial field and lab-based organismal

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systems, but has had limited applicability to deep sea animals. The reasons for this deficit is largely due to the technological challenges to access this environment for study, as well as limited instrumentation that can enable measurements of complex fluid and organismal motion and behavior at the required spatiotemporal scales. To partially address this need, we have recently developed and deployed an in situ lightfield imaging system named *EyeRIS* (Remote Imaging System). This 4000 m-rated instrument provides real-time 3D particle and surface visualizations, and is deployed from a remotely operated vehicle (ROV). Here we describe the first at-sea deployments of the system in the Monterey Bay National Marine Sanctuary, and share how the dynamics of feeding and swimming animals (e.g., squid, ctenophores, sea stars, coral) in the deep sea can be effectively studied.

S4-17 Katti, M*; Mulvey, K L; Caslin, M; Joy, A; Orcutt, D; Eseryel, D; North Carolina State University ; *mkatti@ncsu.edu*

Forests after Florence: a model to engage disaster-impacted students in informal learning through relevant field research

Natural disasters such as hurricanes have lasting impacts on a community, especially the youth. Focusing on academics after a disaster is challenging for students. Research has found high rates of stress in students following various natural disasters. Nearly 15% of NC State University students were impacted by Hurricane Florence in Sep 2018, many from low-income or ethnic minority backgrounds. Science learning that is highly connected with local communities and broader societal issues has been shown to improve student success. Students also value applying STEM training to solve real world problems in their communities, including issues of environmental and social justice. We offered 50 hurricane impacted undergraduate students (from a pool of 4797 impacted by Florence) an informal learning experience to assess their persistence, resilience, and STEM identity. In Summer 2019, students worked in pairs over 2 weeks to collect community-relevant forest impact data in their home counties: 360° photographs of hurricane damage to trees for 3DVR analyses, oral history recordings from community, and GIS to map hurricane impacts. We used pre-/post-tests to evaluate changes in students' learning, science identity, persistence, and resilience. Students reported a growth in science

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identity, knowledge of trees and climate change, and in perceptions that science can be used to effect change in local communities. Students also experienced a boost in science interest and identity on days when they had positive field experiences. Post-disaster interventions using relevant research learning experiences can thus play an important role in helping students recover from disasters.

BSP-8-10 Kaushik, PK*; Renz, M; Olsson, SB; National Centre for Biological Sciences, Bengaluru, Universität Bielefeld, Bielefeld; *pavan@nice.ncbs.res.in*

Getting nature inside the lab using virtual reality

The exemplary search capabilities of flying insects have established them as one of the most diverse taxa on Earth. However, we still lack the fundamental ability to quantify, represent, and predict trajectories under natural contexts to understand search and its applications. For example, flying insects have evolved in complex multimodal three-dimensional (3D) environments, but we do not yet understand which features of the natural world are used to locate distant objects. Here, we independently and dynamically manipulate 3D objects, airflow fields, and odor plumes in virtual reality over large spatial and temporal scales. We demonstrate that flies make use of features such as foreground segmentation, perspective, motion parallax, and integration of multiple modalities to navigate to objects in a complex 3D landscape while in flight. We first show that tethered flying insects of multiple species navigate to virtual 3D objects. Using the apple fly *Rhagoletis pomonella*, we then measure their reactive distance to objects and show that these flies use perspective and local parallax cues to distinguish and navigate to virtual objects of different sizes and distances. We also show that apple flies can orient in the absence of optic flow by using only directional airflow cues, and require simultaneous odor and directional airflow input for plume following to a host volatile blend. The elucidation of these features unlocks the opportunity to quantify parameters underlying insect behavior such as reactive space, optimal foraging, and dispersal, as well as develop strategies for pest management, pollination, robotics, and search algorithms.

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96-5 Keathley, CM*; Moon, BR; University of Louisiana at Lafayette; *christina.keathley@gmail.com*

Electroreception in amphiuma salamanders

Ampullary organs are electroreceptive sensory organs embedded in the lateral line system of many aquatic vertebrates and work by detecting electrical signals emitted into the water by other nearby organisms. These organs are used in migration, predator avoidance, and mate detection, but are most notably used to locate and acquire prey. While most research on ampullary organs has been conducted in teleost and elasmobranch fishes, aquatic salamanders also possess these specialized organs. Previous studies have given detailed histological descriptions of ampullary organs in salamanders, but very few have investigated the effects of this sensory information on an animal's behavior. We exposed two-toed amphiuma (*Amphiuma means*) and three-toed (*Amphiuma tridactylum*) amphiuma salamanders to low-voltage, alternating and direct currents in water at different frequencies to test for behavioral indications of electroreception and potential feeding responses. Because amphiuma salamanders live in murky waters, are active at night, and spend long periods of time in burrows, sensory information other than sight may be important for movements and especially feeding. Our amphiumas showed behavioral responses, including likely feeding responses, to the electrical signals. These results will help determine the sensitivity and behavioral importance of ampullary organs in amphiuma salamanders, and highlight the value of testing for electroreception in other aquatic salamanders.

45-5 Keaveny, EC*; Rowe, E; Rule, DC; Dillon, ME; University of Wyoming ; *ekeaveny@uwyo.edu*

Lipid composition of bumble bees and their pollen diets: bees are (mostly) what they eat

Bumble bee success in diverse thermal environments, from the tropics to the poles and from sea level to the highest mountaintops, depends in part on their heterothermic lifestyle. They endogenously regulate high temperatures for flight, foraging, and incubation, but can also shut down to save energy via ectothermy. Maintaining cellular function at different temperatures often requires membrane remodeling, such that fluidity and the myriad cellular processes that depend on it stays in an optimal

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range. Shifts in fatty acid (FA) composition are often a primary mechanism for maintaining membrane fluidity in changing temperatures, with shifts from saturated to unsaturated FA as organisms move from hot to cold, respectively. This homeoviscous adaptation may, however, be constrained by diet. To address the link between diet and lipid composition in bumble bees, we used two complementary approaches. First, we compared FA composition of flight muscle of bees reared in the lab (*Bombus impatiens*) with FA composition of their pollen diet (both determined by GC-FID). Second, we compared FA composition of wild-caught worker bees (*B. huntii* and *B. griseocollis*) with FA composition of their pollen baskets. Both lab-reared and wild-caught bees were enriched in longer chain, unsaturated FA relative to their pollen diet, likely reflective of enzymatic pathways described in other insects (elongases, desaturases). Despite carrying pollen with similar FA composition, wild species differed in FA composition. Combining diet experiments with thermal challenges will help us better elucidate the influence of diet on membrane remodeling in response to temperature fluctuations these widespread pollinators must often face.

48-7 Keeley, SC*; Funk, VA; Cantley, JT; University of Hawaii at Manoa, Honolulu, HI, Smithsonian Institution, Washington, DC, San Francisco State University, San Francisco, CA; *sterling.keeley@gmail.com*

Overview of the origin and evolution of compositae of Pacific Oceania

The Pacific Islands are well known for their role in the study of evolution.The source areas of ancestors of their endemic biotas and how they arrived on these isolated land masses is also of great biogeographical interest.The Compositae is the largest family of flowering plants in the world (~25000 spp).It is well represented in Pacific Oceania making it an ideal group to study dispersal and evolution.A database was constructed using herbarium specimens, literature, online sources, published floras, checklists, revisions and monographs to catalogue all known Pacific Compositae.Combining this with recent phylogenetic information we inferred the natural range of each taxon and their area of origin.We found 39-44 lineages native to Pacific Oceania with 176 species in 36 genera

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for which 174 had sufficient information to determine their origins. Of these, 158 species are endemic to either Hawaii or SE Polynesia. Thirteen-14 lineages originated from SE Asia or Asia, 14-18 from Australia, New Guinea, New Zealand, and 6-7 from western North America. These source areas are similar to those reported for the Hawaiian flora as a whole, although some, including the Neotropics, do not appear to be sources of Compositae. Per considerable discussion of theoretical ideas on island evolution, Pacific taxa of Compositae comprise several well known cases of adaptive radiation (silverswords, *Bidens*), often accompanied by movement from coastal to montane habitats. They also exemplify other classic examples of insular evolution. For instance, loss of dispersibility is well documented in *Bidens* and evolution of woodiness from herbaceous ancestors is documented in *Fitchia* and *Artemisia*. Shifts in sexual systems to promote outcrossing and/or self-incompatibility also occur.

45-4 Keicher, L*; Shipley, JR; Komar, E; Schaeffer, PJ; Dechmann, DKN; Max Planck Institute of Animal Behavior, Am Obstberg 1, 78315, Radolfzell, Germany, Mammal Research Institute, Polish Academy of Sciences, 17-230 Bialowieza, Department of Biology, Miami University, Oxford, OH 45056, USA; *lkeicher@ab.mpg.de*

High resolution heart rate data reveal novel energy saving strategy in temperate-zone bats

Torpor is a widely used energy saving strategy in small heterothermic mammals. Measuring body temperature is a common method used to infer energy consumption and torpor use. However, it has recently been shown that heart rate is a more accurate predictor of metabolic rate than body temperature in two tropical bat species. To put these findings into a broader context, we simultaneously measured continuous heart rate, body temperature and metabolic rate in females from a temperate zone bat species (*Nyctalus noctula*). We investigated energy saving strategies across three reproductive stages at seasonal and varied ambient temperatures. We found that pregnant bats lowered their body temperature to adapt to ambient temperatures less often than non-reproductive bats. Instead they were able to independently lower their heart rate to save energy. We confirm that heart rate better predicts metabolic rate than the traditionally used body

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temperature and show that across all reproductive stages, bats can express very low heart rates at high body temperatures. With these novel findings in a temperate bat species, bats from at least three different families can flexibly adapt their physiological state to current life history stage and ambient conditions, saving energy through adjusting heart rates independently of body temperature. This emphasizes the need to revise the definition of torpor as an energy saving strategy.

110-11 Keirnan, AR*; Weisbecker, V; Iwaniuk, AN; Flinders Univ, Australia, Univ Lethbridge, Canada; *keir0008@flinders.edu.au*

The nocturnal letter-winged kite (Elanus scriptus) and diurnal birds of prey: visual anatomy differences are not like night and day

Evolutionary shifts from diurnal to nocturnal niches are often associated with visual system change. Under low-light conditions, retinal sensitivity increases, triggering corresponding changes in the optic nerve and retinorecipient brain regions. In birds, these changes are not only evident in the soft tissues of the nervous system, but also skull morphology. Thus, skull measurements can be used as a proxy for some aspects of sensory system evolution in nocturnal species. Here, we use this approach to infer the visual abilities of the letter-winged kite (LWK; *Elanus scriptus*). This species is the only nocturnal hawk and is thought to possess several owl-like anatomical traits. Using μCT scans, we reconstructed endocasts of LWKs and 14 diurnal hawk and falcon species and acquired measurements of the visual system from the endocasts and skulls. In contrast to many other nocturnal birds, the LWK did not differ from diurnal species in the relative size of its orbits, optic foramina or optic lobes. We also did not detect any differences in orbit orientation between the LWK and other species, including its congener (*Elanus axillaris*). Nocturnal foraging in LWKs might therefore be facilitated by more subtle anatomical changes, such as rod:cone ratio, than what is observed in many other nocturnal bird species. However, without accompanying changes in osteology that we could detect, the LWK is unlikely to have the visual sensitivity typical of other nocturnal avian predators, such as owls. We conclude that not all nocturnal birds evolved large changes in skull morphology and therefore inferring

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activity patterns of extinct species may not be possible from osteology alone.

26-2 Keith, A*; Khudyakov, J ; Codde, S; Vierra, C; Crocker, D; Department of Biological Sciences, University of the Pacific, 3601 Pacific Ave., Stockton CA 95211, Inventory & Monitoring Program, Point Reyes National Seashore, 1 Bear Valley Rd, Point Reyes Station, CA 94956, Department of Biology, Sonoma State University, 1801 E. Cotati Ave., Rohnert Park, CA 94928; *annarenekeith@gmail.com*

Molecular responses to catastrophic molting in a marine mammal

While most mammals shed their hair and skin either continuously or seasonally, northern elephant seals *(Mirounga angustirostris)* undergo an annual catastrophic molt, in which they shed their entire fur and underlying skin layer in the span of just three weeks. Due to the energetic and thermoregulatory constraints of molting and the large distances between their coastal rookeries and foraging grounds, elephant seals must remain on land and fast for the duration of their molt. Previous studies of molting northern elephant seals have examined endocrine and metabolic adjustments to fasting, but not the molecular processes underlying molting. We examined changes in the skin and underlying blubber proteomes during molting to provide a more in-depth understanding of the cellular mechanisms enabling rapid skin shedding and regeneration in this marine mammal. Shotgun proteome sequencing by LC-MS/MS identified 48,078 peptides and 755 protein groups in skin and blubber that were associated with proteasome degradation, gluconeogenesis, and the Hippo cell signaling pathway. Label-free quantification and differential protein expression analyses identified 191 and 360 proteins that were differentially expressed over molting in the skin and blubber. Proteins upregulated in late molt skin included those associated with inflammation, amino acid synthesis, and angiogenesis. Proteins upregulated over molting in blubber included those associated with fat catabolism and fructose metabolism. This suggests that rapid skin regeneration involves intensive protein synthesis and increased vascularization that may be supported by fatty acid metabolism from underlying blubber tissue. These data provide insights into molecular mechanisms that govern unusually rapid skin regeneration in mammals, which may

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further understanding of disorders affecting the skin and hair of humans and other mammals.

60-3 Kelly, TR*; Vinson, AV; Lattin, CR; Louisiana State University, Baton Rouge, LA; *trkelly@lsu.edu*

No guts about it: captivity, but not neophobia phenotype, affects cloacal microbiome of house sparrows

With increasing human development and urbanization, wild animals more frequently encounter novel objects and novel foods, and an individual's hesitation to approach a new object or food (neophobia) can affect their survival. Individual house sparrows (*Passer domesticus*) vary markedly in their behavioral responses to novel objects and foods, and we hypothesized neophobia phenotype could affect cloacal microbiome. We exposed house sparrows (n=24) to a suite of novel objects and foods, assessed their behavioral phenotypes (neophobic vs. non-neophobic), and examined whether phenotype affected cloacal microbiome before and after captivity. We predicted non-neophobic birds would have higher alpha and beta diversity than neophobic individuals prior to captivity due to consumption of a more diverse wild diet. Because all birds experienced a nearly identical diet during captivity, we predicted no differences between phenotypes post-captivity. We identified 4642 unique OTUs in neophobic and non-neophobic individuals. Alpha and beta diversity of neophobic and non-neophobic phenotypes did not differ before or during captivity. Exposure to captivity reduced alpha diversity of both phenotypes and caused beta diversity to become more homogeneous: six bacterial phyla were dominant in wild samples (Proteobacteria, Firmicutes, Verrucomibrobia, Actinobacteria, Chlorobi, and Bacteroidetes) but only two were dominant during captivity (Firmicutes and Actinobacteria). In summary, while we did not detect effects of neophobia phenotype on the cloacal microbiome in house sparrows, our results highlight significant alterations to the microbiome after transition to captivity for this songbird, in the opposite pattern of previous reports in parrots and raptors.

S2-7 Kelly, MW*; Smith, HN; Sirovy, KA; LaPeyre, JF; List, SM; Johnson, KM; Louisiana State University, California Polytechnic

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Testing how broad physiological tolerances are shaped by selection: transcriptomic variation in salinity, temperature, and hypoxia responses in the eastern oyster

Even for a euryhaline invertebrate, the eastern oyster (*Crassostrea virginica*) inhabits an especially broad range of conditions. Its geographic range extends from the Gulf of St. Lawrence, Canada, to the Gulf of Mexico, where it inhabits estuaries with salinities ranging from 4-35 PSU, and annual water temperatures ranging from -2 degrees C to 36 degrees C. In some organisms, this kind of broad tolerance is achieved with a single 'general purpose' phenotype, capable of surviving all conditions, whereas in others, broad tolerance at the species level is achieved through local adaptation, where a series of populations are each optimized to their individual conditions, collectively comprising a species with broad tolerance. We tested these competing scenarios in a series of three experiments, each comparing the physiological and transcriptomic responses to a single stressor (either hypoxia, low salinity, or high temperatures) between populations of *C. virginica* that differed in their histories of exposure to that stressor. While a portion of the transcriptomic response to each stressor was unique to individual populations, we observed a strong signature of parallel physiological and transcriptomic responses to stress across populations. Genes involved in transcriptomic response to stress also tended to have lower Ka/Ks values, suggesting purifying selection. Taken together, our results suggest that the broad environmental range of *C. virginica* is achieved through a set of conserved physiological responses to environmental stress, and that these responses are largely shared across disparate populations.

85-9 Kelly, PW*; Pfennig, DW; Pfennig, KS; University of North Carolina at Chapel Hill; *patk@live.unc.edu*

Adaptive plasticity as an indirect fitness benefit of mate choice in variable environments

Whether sexual selection can promote adaptation in variable environments is unclear. Sexual selection can promote adaptive evolution when adult sexual traits predict offspring fitness, but environmental variation is expected to break down associations

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between sexual traits and offspring fitness. If, however, adult sexual traits predict adaptive offspring plasticity, then sexual selection can promote adaptation in the face of environmental variation. Here, we present data demonstrating that mate preferences of female spadefoot toads (*Spea multiplicata*) predict offspring plasticity and fitness across natural populations. Specifically, in populations where more females prefer exaggerated forms of a condition-dependent male sexual signal, tadpoles are more likely to express an inducible resource-use phenotype and grow larger. We additionally present experimental evidence that condition-dependent male sexual signals covary with the expression of tadpole plasticity and tadpole fitness. Our findings provide evidence that plasticity can serve as an indirect benefit of mate choice in variable environments. Our data also suggest that mate preferences for traits indicative of offspring plasticity can maintain associations between sexual traits and offspring fitness, thereby highlighting how sexual selection and plasticity can interact to facilitate adaptation even in heterogeneous environments.

22-6 Kennedy, KN*; Hall, KC; Cohen, KE; Donatelli, CM; Kruppert, S; Kolmann, MA; Univ. of California, Berkeley, Univ. of Washington, Friday Harbor Labs, Univ. of Ottawa, Univ. of Michigan; *kathryn.kennedy@berkeley.edu*

Mighty fine spines: trade-offs in puncture performance among spiny cartilaginous fishes

Fossil acanthodians had mineralized fin spines on several or all of their fins. Yet extant species of chondrichthyans only have spines on their dorsal fins, if at all. Fin spines serve multiple functions, sometimes stiffening a fin's leading edge, but typically used as a defensive puncture tool. The diversity of fin spines among species begets the question whether certain morphotypes (recurved or straight) and macrostructures (serrations and keels) perform better for certain functions. To address the defensive providence of these spines, we compared puncture performance among three chondrichthyan species (ratfish *Hydrolagus colliei*, horn shark *Heterodontus francisci*, and dogfish *Squalus suckleyi*) using 3D-printed spine models mounted on a Material Testing System. We measured the force and work incurred during puncture and withdrawal

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of spines from gelatin mimicking animal flesh. Our results showed that thicker, blunter spines (horn shark) required the most force to puncture, therefore acting as the worst "stabbers" and best crack propagators. Recurved spines (dogfish, ratfish) and spines with serrations (ratfish) required the most force to withdraw, suggesting that these spines cause more damage upon removal or are not meant to be dislodged at all. Ratfish and posterior dogfish spines performed similarly, while the posterior and anterior spines of dogfish behaved differently, demonstrating functional convergence as puncture tools in the former and the alternative role of fin stiffeners in the latter. As many acanthodian spines were recurved and serrated, our findings in modern chondrichthyans suggest that these spines would have been difficult to dislodge and would have caused serious damage to extinct predators.

57-6 Kennedy, J*; Chen, C; Mahadevan, L; Nagpal, R; Harvard University School of Engineering and Applied Sciences, Harvard College ; *jokennedy@g.harvard.edu*

Mapping spatiotemporal changes of North American beaver (L. Castor canadensis) damming complexes

Beavers construct structurally complex and dynamic damming networks. Beaver increase biodiversity by providing habitat for many species of waterfowl, wildlife, fish and invertebrates through dam building activities. Beaver are able to completely reshape their surroundings. In mountainous regions snow melt annually washes out the previous year beaver builds. Beaver colonies thrive by recapitulating the entire dam building process over a period of three to five months. We present a study of beaver colony damming network construction in the foothills of the Rocky Mountains in northwestern Montana. Using a combination of hydraulic measurements and aerial imagery we observed the construction activities of beaver during their active building season. To observe dam building at high enough spatial and temporal resolution we used a DJI Phantom 4 Pro drone to conduct weekly scans of four sites from May 2018 to August 2018, covering approximately 103 hectares, 17 beaver colonies responsible for the construction of 76 dams over a three month period following snow melt. We constructed high resolution (1.3 cm/px) orthomosaics which were then annotated in order to track dam network formation and growth. Results suggest that the

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initiation of building corresponds to the measured volumetric flow rates at each site. Beaver engage in dam building when the volumetric flow rates were between 0.2 m3/sec and 0.5 m3/sec. Beaver appear to build on existing or washed out dams before nucleating the build of new damming sites. The majority of dams were built downstream of the beaver lodge. The final damming complex is many times larger than any one individual beaver and likely taking place in many locations simultaneously.

S1-10 Kernbach, ME*; Martin, LB; Unnasch, TR; Hall, RJ; Jiang, RHY; Francis, CD; University of South Florida, University of Georgia, California Polytechnic State University; *Kernbach@mail.usf.edu*
Mechanisms and mitigation: effects of light pollution on West Nile virus dynamics
As light pollution increases in spatial and spectral extent, understanding its widespread consequences for wildlife is more important now than ever. One form of light pollution, artificial light at night (ALAN), dysregulates hormones, hinders immunity, and shifts circadian activity. Therefore, it is surprising that the effects of ALAN on zoonotic diseases, especially those that utilize passerine reservoirs, remain unknown. One of the most important passerine-harbored zoonotic diseases, West Nile virus (WNV), has been linked to properties of peri-urban environments. However, the role of light pollution in this context has never been considered. ALAN-altered host immune responses, combined with effects on vector behavior, may alter transmission potential in such habitats. Previously, we found that house sparrows exposed to low-intensity ALAN maintained infectious WNV titers for longer than controls, which increased outbreak potential. We asked whether these effects manifest ecologically using Florida Department of Health sentinel chicken surveillance data (quantified by WNV antibody seroconversion) and tested the predictive power of multiple environmental parameters on WNV exposure risk. We found that light pollution (as a quadratic function) was a stronger predictor of WNV exposure risk than other measures of urbanization, where cases peak in areas of low-intensity light pollution and decrease in areas of high-intensity light pollution. These data indicate that heterogeneity in ALAN intensity likely an important driver of spatial variation in WNV emergence.

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75-3 Kerr, SJ*; Nicastro, AJ; Zeligs, J; Skrovan, S; Fish, FE; West Chester University, Moss Landing Marine Labs, Moss Landing Marine Labs; *sk927456@wcupa.edu*

Biomechanical energetics of terrestrial locomotion: California sea lion vs. northern elephant seal

Pinnipedia, an order of semi-aquatic marine mammals, adapted a body design to locomote both aquatically and terrestrially. The limbs of these amphibious mammals are modified as flippers, which are beneficial for aquatic locomotion, but can limit their locomotion on land. Phocids, like the Northern elephant seal (*Mirounga angustirostris*), have reduced forelimbs and are unable to bring their hindlimbs beneath them during terrestrial locomotion. Otariids, like the California sea lion (*Zalophus californianus*), have enlarged forelimbs and can bring their hindlimbs under the body to locomote quadrupedally on land. Due to these differences, phocids are expected to move on land with greater energetic costs compared to otariids. These energetic costs would be exacerbated in large phocids, which use an undulatory, crutching terrestrial gait. The energetic cost of terrestrial locomotion in pinnipeds has only been examined in the elephant seal. To compare the mechanical costs of transport of terrestrial locomotion between otariids and phocids, one male and two female adult California sea lions were video recorded galloping across a runway. From these videos, eight anatomical points of reference were digitized to obtain velocity, amplitude of heave, and frequency of oscillations during the gallop cycle. These variables represent the principal parameters of a biomechanical model that computes the power output of individuals. The model indicates that the quadrupedal gait of otariids has a lower cost of transport than the undulatory gait of phocids.

60-8 Ketchum, RN*; Smith, EG; Vaughan, GO; McParland, D; Al-Mansoori, N; Burt, JA; Reitzel, AM; University of North Carolina at Charlotte, UNCC, NYUAD, NYUAD; *rketchu1@uncc.edu*

Unraveling the predictive role of temperature in the gut microbiome of an abundant marine invertebrate

Shifts in microbial communities represent a fast response mechanism for organisms to respond to environmental conditions and are likely

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to be essential in assisting the acclimatization of host species to the increased temperatures associated with climate change. The Persian/Arabian Gulf is the world's warmest sea and therefore may serve as an informative model for predicting how the microbiome will change under climate change conditions. In this study, we investigated temporal and geographic changes in the diversity, stability, and composition of the sea urchin gut microbiome with the aim to identify the main drivers of microbial community variation and identify microbial taxa that are predictive of thermal environment. We generated two independent datasets, the first of which consisted of sampling six different reef sites from the Persian/Arabian Gulf and the Gulf of Oman in both summer and winter. The second dataset sampled one site within the Persian/Arabian Gulf at eight different time points across one year to investigate seasonal microbiome fluctuations. The results show that the gut microbiome is different across thermally variable habitats, displays temporal shifts that correlate with temperature change, and is impacted by temperature through measures of community dispersion. Importantly, the temperature correlation analysis of the two datasets highlighted taxonomic redundancy and in some cases, the exact same microbes, which may point to biomarkers of temperature increases. These results are informative for our understanding of how the environment drives microbial diversity as well as elucidating microbial taxa that may play a key role during thermal stress resilience.

BSP-3-3 Khalil, S*; Houtz, J; Welklin, JF; Schwabl, H; Karubian, J; Tulane U, Cornell U, WSU; *sarah.khalil93@gmail.com*

Testosterone implantation influences gut microbiome diversity, but not diet, in Red-backed Fairywrens

Hormones influence and coordinate a suite of traits in response to environmental or social change. Though there is strong support for the phenotypic-integration role of steroid hormones, only recently have researchers started investigating the relationship between hormones and the microbiome, another host trait known to influence individual fitness. Previous work has demonstrated that gut microbiota can influence hormonal regulation and host behavior, mainly focusing on glucocorticoid hormones and the stress response. Even though androgens, like testosterone, regulate changes in

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physiology and behavior to help match organisms to their social environment, their impact on the gut microbiome is unclear. Using red-backed fairywrens (*Malurus melanocephalus*), a bird in which the effect of testosterone on breeding, behavior and plumage ornamentation is well documented, we tested the hypothesis that testosterone also influences the gut microbiome, possibly through differences in foraging behavior. We collected gut samples from unornamented testosterone-implanted males, unornamented sham-implanted males (controls), as well as females and ornamented males. We measured microbiome and diet diversity (as a proxy for foraging) using DNA metabarcoding. We found that implanted males have significantly lower microbial alpha diversity in the intestine than control males, though there was no difference in diet diversity. Our study highlights the complex ways in which testosterone may influence gut microbiota in relation to different phenotypes, and how testosterone may have direct effects on the microbiome rather than indirect effects through a change in foraging or diet, and warrants further work to disentangle how these relationships influence host fitness.

107-4 Khudyakov, J*; Treat, M; Shanafelt, M; Deyarmin, J; van Breukelen, F; University of the Pacific, University of Nevada, Las Vegas, National Institutes of Standards and Technology; *jkhudyakov@pacific.edu*

Liver proteome responses to hibernation and body temperature variability in a basoendothermic mammal

The common tenrec (Tenrec ecaudatus) is a basoendothermic mammal that displays remarkable plasticity in thermoregulation and metabolism during periods of activity and hibernation. For example, tenrecs can maintain body temperatures as high at 28° C during hibernation and remain active with temperatures as low as 12° C. We compared liver proteomes of active and hibernating tenrecs that maintained either warm (28° C) or cold (12° C) body temperatures using label-free protein quantification by LC-MS/MS. We identified 1,526 protein groups in liver and detected 339 proteins that were differentially expressed between active and hibernating tenrecs. Proteins with higher expression in active tenrecs were associated with amino acid metabolism, fatty acid oxidation, and TCA cycle, while proteins with higher expression in hibernating tenrecs

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included those involved in proteasome degradation, gluconeogenesis, and ketone metabolism. Hibernating tenrecs displayed high individual variability in protein expression that did not differ between cold and warm animals. In contrast, protein expression was consistent within active groups and differed between warm active and cold active animals. Proteins with higher expression in warm active tenrecs included heat shock proteins and antioxidant enzymes, while those upregulated in cold active tenrecs included haptoglobin and translation initiation factors, suggesting that active animals with lower body temperatures may be transitioning into hibernation. Together, these data suggest that metabolic homeostasis may not be tightly maintained during hibernation in a basoendothermic mammal, unlike in boreal hibernating species.

101-1 Kiat, Y*; Sapir, N; Department of Evolutionary and Environmental Biology and the Institute of Evolution, University of Haifa, Israel; *yosefkiat@gmail.com*

Passerine feather molt extent is affected by temporal and spatial variation of climate

Temporal and spatial environmental variation shapes organisms, populations and ecosystems. In birds, global warming and climate gradients across large spatial extents alter the properties of different annual-routine processes, including reproduction, molt and migration. Juveniles of most passerines species replace their nest-grown plumage partially during the first months of their life, a process that is called post-juvenile feather molt. This molt may largely determine the individual appearance, influencing, for example, bird attractiveness, social status and camouflage. Using field-data from several localities in the Palearctic regions, as well as museum data from 11 natural history collections, we show that the extent of the post-juvenile molt (number of feathers molted) has increased significantly over the last 200 years, a trend that is positively correlated with the temperature of the environment. In addition, we found that among passerines, post-juvenile molt extent differs between the Western and the Eastern Palearctic zones. This difference is most likely the result of a large-scale climatic gradient in cold season duration and consequently the time available for molting. Our results indicate that birds replaced more feathers under warmer conditions, causing

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juveniles to appear more similar to adult birds. These results highlight the analogy between temporal and spatial responses to climate differences, and as such may improve our understanding of various impacts of global climate change on avian life-history properties and the evolution of annual-routine scheduling of different processes such as breeding, molt and migration.

S10-5 Kiger, KT; University of Maryland; *kkiger@umd.edu*
Pumping by oscillating plates: viscous to inertial transitions in metachronal arrays
External transport and locomotion within biological systems has long recognized that there exists a natural divide between systems dominated by viscous flow and that dominated by inertia. In simple single or paired appendages, this typically takes the form of a either a rowing type of kinematics for viscous low Reynolds numbers conditions (*Re* ≪ 1), with the forces generated in the direction of the stroke, whereas for inertially dominated high Reynolds number conditions (*Re* ≫ 1) a flapping type motion produces forces perpendicular to the stroke motion. Inherently, the transition is enabled by a symmetry breaking condition provided by the nonlinear nature of inertially dominated flows. In the viscous dominated flows, the asymmetry must be introduced by the kinematics explicitly, and in metachronal systems this can be introduced by the phasing of the adjacent appendages, as well as by temporal asymmetries in the power and recovery stroke of individual plates, and physical asymmetries due to conformal transformations of the appendage itself. In this work, we examine transitions inspired by the study of mayfly nymphs, which exhibit all of the above effects, as well as looking at similar related systems across different animal systems. This is done first through the study of a representative animal system (*Centroptilum triangulifer*), followed by mechanical and numerical simulations across a broader range of simplification and conditions to better understand how these transitions are enabled and benefit they might provide.

36-1 Kilbourne, BM; Museum für Naturkunde Berlin; *brandon.kilbourne@mfn-berlin.de*

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Functional morphology and diversification of the mustelid hindlimb skeleton and potential influence of differing limb functions

Though form-function relationships of the mammalian locomotor system have been investigated for over a century, recent models of trait evolution have hitherto been seldom used to identify likely evolutionary processes underlying the locomotor system's morphological diversity. Using mustelid mammals, an ecologically diverse lineage within Carnivora, I investigated whether variation in hindlimb skeletal morphology functionally coincides with climbing, digging, swimming, and generalized locomotor habits by using 15 linear traits collected from 44 species. The sampled traits are composed of the lengths, diameters, and muscle in-lever lengths of the femur, tibia, fibula, calcaneum, and metatarsal III, with these traits being used in a principal components analysis. After mitigating the influence of size, I then subsequently fit competing models of Brownian motion and adaptive trait diversification individually to each of the 15 traits. Mustelids specialized for climbing occupy a region of phenotypic space characterized by a gracile limb skeleton, whereas those specialized for digging and swimming occupy regions characterized by a robust limb skeleton though of differing limb proportions. A model of adaptive evolution is the most likely fit for individual traits of the hindlimb; however, simulating data under models of best fit and fitting the simulated data to the different diversification models reveals low statistical power to rank the models. Though the differences in hindlimb skeletal morphology appears to coincide with locomotor habits, further study, with sampling expanded beyond Mustelidae and including fossil taxa, is necessary to better understand to what degree adaptive evolution shapes the morphological diversification of the locomotor system in mustelids and other mammals.

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82-3 Kimball, MG*; Kelly, TR; Stansberry, KR; Lattin, CR; Louisiana State University ; *mkimba6@lsu.edu*

Neural expression of two immediate early genes do not differ in response to novel objects in neophobic and non-neophobic house sparrows (Passer domesticus)

Neophobia is a specific type of exploration-avoidance behavior, and it is a personality trait with critical ecological relevance, because it affects whether animals will be able to adapt to new environments and exploit novel resources. Despite its importance, the neurobiological mechanisms underlying neophobia are still poorly understood. In this study we examined regional brain activity using immediate early gene (IEG) expression in response to novel objects in captive house sparrows (*Passer domesticus*, n=24). We predicted non-neophobic individuals would show decreased neuronal activity in brain regions involved in fear and anxiety (e.g., nucleus taeniae of the amygdala), and increased activity in brain regions involved in learning and memory (e.g., striatum) than neophobic individuals. To classify birds by phenotype, we used behavior trials that tested willingness to approach a food dish in the presence of several different novel objects, habituation to one novel object, and willingness to try novel foods. We then exposed birds to a new novel object and assessed protein expression of two IEGs in neophobic vs non-neophobic individuals after this final exposure. Sparrows showed clear phenotypic distinctions, with a third of individuals showing highly neophobic behavior, a third highly non-neophobic behavior, and a third intermediate behavior. There was also high repeatability of novel object responses (r=0.51). However, we saw no differences between neophobic and non-neophobic birds in IEG expression in response to novel objects in any of the 5 brain regions examined. This suggests that neophobia is not caused by different patterns of overall activity in brain regions involved in responding to threats, learning, or memory.

88-3 King, TP*; Maruska, KP; Louisiana State University ; *tking21@lsu.edu*

Social and reproductive state influences the immune response in an African cichlid fish

To ensure survival, individuals constantly evaluate trade-offs between crucial biological systems, like the reproductive and immune systems. However, little is known about how social species balance interactions between immune system function and fluctuations in social status and reproductive fitness, particularly in fishes, the largest and most diverse group of vertebrates. The cichlid fish Astatotilapia burtoni is ideally suited to address this question because males and females cycle through social and reproductive states characterized by different

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physiologies. Here, we tested the hypothesis that immune responses differ with sex, social rank and reproductive state. Fish were injected near the caudal peduncle with phytohaemagglutnin (PHA), a lectin that stimulates localized inflammation, and changes in the width of the injection site were quantified. We show that reproductively-suppressed subordinate males have a greater change in the width than reproductively-active dominant males, indicative of the recruitment of more leukocytes and a stronger immune response, but there was no difference between males and females. Sectioned spleens in both sexes also showed differences in the quantity of macrophage centers, a marker of adaptive immunity, between PHA and vehicle-injected animals. Using qPCR, we also compare expression levels of pro-inflammatory cytokines in spleen and kidney of immune-challenged animals. Because little is known about how reproductive physiology influences immune responses in fishes, this research provides greater insight into how socially plastic animals' balance these trade-offs, with important implications for other taxa that exist in dominance societies.

46-4 King, EE*; Stillman, JH; Williams, CM; University of California, Berkeley, University of California, Berkeley and San Francisco State University; *emily_king@berkeley.edu*

Hot and short of breath: High temperature and hypoxia regulates performance and habitat range in an invasive snail

Predicting how climate change will affect a species' range, which is already shaped by environmental stress tolerance, is a central problem in eco-physiology, especially for invasive species. We address this problem using the globally invasive aquatic snail, *Potamopyrgus antipodarum*, as a model. Whether a site is likely for future invasion depends on *P. antipodarum's* tolerance to the dissolved oxygen (DO) and temperature at that site. We previously investigated the effects of temperature and DO on respiration and locomotion to understand what conditions limit fitness related traits. We found that extreme temperatures limited both respiration and locomotion, but that hypoxia limited respiration to a greater extent than locomotion. Locomotion under warm, hypoxic conditions may be fueled anaerobically and thus, time limited. The current study draws on the physiological limits determined in the lab to see if limiting conditions already exist

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in the field. We predicted that high temperatures and hypoxia would co-occur with small populations. We monitored the temperature and DO conditions in three streams in different San Francisco Bay Area microclimates for one year. In each stream there were sites with dense and sparse snail populations. We found that sites with dense snail populations had the highest overall temperatures and were commonly hypoxic, with some exhibiting anoxia for several hours at a time. Sites with few snails exhibited mild conditions. Overall, the current environmental conditions in each region support snail populations, but future warming and hypoxia may constrain population growth at the warmest sites by reducing thermal safety margins.

81-3 King, JL*; Rayfield, EJ; Benton, MJ; University of Bristol, Bristol; *jk17345@bristol.ac.uk*

Ontogenetic trends in the endocranial flexure of archosaurs

Flexure angles of the cranial endocast are defined as cephalic flexure (the angle between the olfactory bulbs, cerebrum, and oblique axis of the midbrain) and pontine flexure (the angle between the medulla oblongata, oblique axis of the midbrain, and cerebrum) and can be summarised as the angles between the forebrain and midbrain, and hindbrain and midbrain, respectively, within archosaurs. Flexure angles in the avian endocast remain approximately consistent through ontogeny, while flexure angles in crocodilian endocasts increase through ontogeny. Considering the relationship of non-avian dinosaurs to both birds and crocodilians, endocranial flexures of non-avian dinosaurs are typically described as either "avian" -like or "crocodilian/basal archosaur" -like. Here we present a study of six (ostriches, chickens, alligators, caiman, *Tyrannosaurus*, *Psittacosaurus*, and *Dysalotosaurus*) different archosaur ontogenetic series (n=29) demonstrating that while flexure angles from individual specimens can be compared to the angles found in birds or crocodilians, ontogenetic trends in flexure change are not so simple. All clades of non-avian dinosaur sampled in this study diverged from the developmental patterns assumed from modern analogues. While the fossil record of dinosaur ontogenetic endocrania is currently too fragmentary to claim that trends in flexure change are phylogenetic, it is clear that changes in cephalic and pontine flexure angles of non-avian dinosaurs

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though ontogeny are neither constant nor always follows a constant increase throughout postnatal development. This indicates that ontogeny is just as important as phylogeny in terms of endocranial morphology within Archosauria. Our understanding of endocranial evolution within a species can be skewed - or even incorrect - without knowing the age of a specimen from which an endocast is made.

61-2 Kingsolver, JG; Univ of North Carolina, Chapel Hill; *jgking@bio.unc.edu*

Overture for George Gilchrist

George Gilchrist had a distinguished career in evolutionary biology as a researcher, educator, and leader. He also had a remarkable range of passions and interests, from kites and kilts to wine and opera. After a brief overview of his training and positions, I will discuss three aspects of his George's career that intersected with my own: His ground-breaking graduate studies on variation and evolution of thermal performance curves; his dedication to scientific synthesis, and his sabbatical at NESCent (National Evolutionary Synthesis Center); and his devotion to mentoring at all levels throughout his career. We will close with a brief discussion of Wagner's *Ring*, music that George greatly admired.

94-7 Kingston, ACN*; Chappell, DR; Speiser, DI; University of Tulsa and University of South Carolina, University of South Carolina; *acnahm@gmail.com*

A snapping shrimp has the fastest vision of any aquatic animal

Animals use their sensory systems to sample information from their environments. The physiological properties of sensory systems differ, leading animals to perceive their environments in different ways. For example, eyes have different temporal sampling rates, with faster-sampling eyes able to resolve faster-moving scenes. Eyes can also have different dynamic ranges. For every eye, there is a light level below which vision is unreliable because of an insufficient signal-to-noise ratio and a light level above which the photoreceptors are saturated. Using electroretinography (ERG), we investigated the temporal sampling and dynamic range of the eyes of the bigclaw snapping shrimp, *Alpheus heterochaelis*. Here, we

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report the eyes of *A. heterochaelis* have a temporal sampling rate of at least 160 Hz, with the eyes of some individuals performing up to 200 Hz. Our results show that *A. heterochaelis* has the fastest-sampling eyes ever described in an aquatic animal. Fast-sampling eyes help flying animals detect objects moving across their retinas at high angular velocities. *A. heterochaelis* are fast-moving animals that live in turbid, structurally complex oyster reefs and their fast-sampling eyes, like those of flying animals, may help them detect objects moving rapidly across their retinas. We also report the eyes of *A. heterochaelis* have a broad dynamic range that spans conditions from late twilight (~ 1 lux) to direct sunlight (~ 100,000 lux), a finding consistent with the circatidal activity patterns of this shallow-dwelling species.

54-8 Kinsey, CT*; Blob, RW; Clemson University; *ckinsey@clemson.edu*
A novel behavior upsets the adaptive peaks hypothesis in metamorphic frogs

Metamorphic animals can experience transitional periods in morphological development that impair aspects of functional performance. Such hurdles can reduce survival and fitness of intermediate developmental stages, a pattern termed the adaptive peaks hypothesis. The metamorphic tadpoles of frogs have been a prominent model for the study of this hypothesis. With the potential for interference between the two propulsive systems (tail and legs) present during peak metamorphosis, locomotor performance and survival could be reduced during this stage. Though previous studies have focused on generalist taxa like ranids, the adaptive peaks hypothesis has been accepted across Anura, with little attention given to species with different lifestyles. We addressed this gap through studies of the pipid *Xenopus laevis*, an aquatic specialist. We recently reported an increase in swimming performance and survival through metamorphosis, unlike more generalist frogs. These results suggest the adaptive peaks hypothesis does not apply as broadly as once thought, potentially because both the tail and limbs contribute to propulsion. However, statistical comparisons of filmed predation trials shows that more developed tadpoles and froglets are as likely to be captured as less developed tadpoles when attacked by cichlid fish. Thus, the increased survival of later stage *Xenopus* cannot be attributed

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solely to increased locomotor performance. Instead, older captured tadpoles are often spat out, potentially after kicking with clawed hind limbs and scratching the oral cavity of the fish. These observations reinforce our proposal that the adaptive peaks framework does not apply to all metamorphic frogs. Additional mechanisms may affect survival and the morphology-performance-fitness paradigm in the context of metamorphosis.

41-5 Kissane, KC; Trinidad State Junior College; *kelly.kissane@trinidadstate.edu*

Teaching during a pandemic: observations of students' reactions to different teaching formats

The pandemic forced biology instructors to move traditionally face to face classes to online or hybrid formats. How students responded to this shift depended highly on their age and personality. My observations of students reactions to this shift in course formats indicated that young undergraduates did best when the course was highly structured, the instructions were clear and consistent, and the material presented in a hybrid format rather than a 100% online format. I share my observations and give examples of student reactions to changing course formats.

BSP-6-1 Klabacka, RL*; Parry, HA; Yap, KN; Cook, RA; Heron, TA; Horne, LM; Maldonado, JA; Oaks, JR; Kavazis, AN; Fujita, MK; Schwartz, TS; Auburn University Department of Biological Sciences and Auburn University Museum of Natural History, Auburn, AL, Auburn University School of Kinesiology, Auburn, AL, Villanova University Department of Biology, Villanova, PA, University of Missouri College of Veterinary Medicine, Columbia, MO, University of Texas at El Paso Department of Biology, El Paso, TX, University of Texas at Arlington Department of Biology, Arlington, TX, Auburn University Department of Biological Sciences, Auburn, AL; *klabacka.randy@gmail.com*

Reduced endurance and mitochondrial respiration in hybrid asexual lizards (genus: Aspidoscelis)

The indisputable scarcity of asexual vertebrates alludes to an inherent cost incurred in asexual reproduction. Cellular respiration, the mechanism by which eukaryotes generate energy in

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the form of ATP, functions by harnessing subatomic energy via an electron transport system made up of co-evolved protein subunits of mitochondrial and nuclear origin. Asexual lineages lack the ability to efficiently filter autosomal alleles via genetic recombination, and thus are predicted to gradually lose compatibility between mitochondrial and nuclear genomes. The universal need for energy among eukaryotes suggests that this intragenomic network may contribute to the scarcity of asexual vertebrates. Alternative hypotheses include genomic incompatibilities due to the hybrid origins of essentially all parthenogenetic vertebrates. With asexuals constituting one third of its ~45 species, the genus *Aspidoscelis* (whiptail lizards) is a great model system for testing costs of asexuality. Here we measure endurance capacity in five species of *Aspidoscelis* and examine mitochondrial respiration between sexual and asexual species using live mitochondria respirometry. Our results show reduced endurance and mitochondrial respiration in asexual lineages compared to parental sexual lineages. We discuss these findings in the context of evolutionary history and mitonuclear co-evolution.

71-7 Klein, SM*; Chase, HT; Tobalske, BW; University of Montana, Missoula; *smklein114@gmail.com*

Investigating chukar ontogeny can shed light on flight evolution and form-function relationships

Understanding how flight capacity increases in extant birds throughout ontogeny can provide crucial insight into the evolutionary transitions of flight. Using this approach, Wing-Assisted Incline Running was proposed as an evolutionary model after studying the development of flight capacity in Chukars, a precocial bird that flaps to run up steep inclines for refuge. In Chukars, flight capacity increases ontogenetically as locomotor investment shifts from hindlimbs to forelimbs. In the wing, increases in lift production and an adult flight stroke are facilitated as joints ossify and become more kinematically restricted. However, the structure of these developing joints and their relation to functional transitions in flight capacity remains unknown. We thus sampled Chukars at various age points to investigate these joints throughout ontogeny, focusing on the trabecular bone in the epiphyses. Trabecular matrix has been shown

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to structurally adapt to an organism's function throughout ontogeny with high sensitivity, providing functional signals that correlate with behavior at various developmental stages. We collected microCT scans of 3 humeri and femurs at 6 age points (2dph-adulthood). As ossification increased across age, we were able to separate between developmentally and functionally relevant trabecular bone. Preliminary results show a functional signal with a notable shift near the age flight capacity becomes adult-like. Ongoing work continues to explore functional signals in the humeral matrix as well as in the proximal femur. This approach provides a better understanding of the ontogenetic functional morphology of flight and deeper insight into the roles of developmental processes and hindlimb-forelimb tradeoffs over flight acquisition in birds- both ontogenetically and evolutionarily.

5-4 Kloepper, LN*; Bentley, I; Harding, C; Taylor, GK; Saint Mary's College, Oxford University, Oxford University; *lkloepper@saintmarys.edu*

What is it like to be a bat: the physics of flight during high-speed roost re-entry in the Mexican free-tailed bat (Tadarida brasiliensis)

Mexican free-tailed bats (Tadarida brasiliensis) are believed to be the fastest moving mammals on Earth, reaching speeds exceeding 100 km/h during roost re-entry. Although the speeds of returning bats have been documented, the kinematics and echolocation behavior during high-speed flight are relatively unknown. Using a camera system synchronized to an ultrasonic microphone, we extracted the 3D position of 26 individual bats as they returned to their cave roost in New Mexico, USA. From the location of the body in each frame we determined instantaneous kinematic parameters including velocity, tangential and centripetal acceleration, flight curvature, and accelerations in terms of the gravitational constant g. Corresponding acoustic parameters including call duration, frequency, interval and time delay of received echoes were also calculated. Bats returned at speeds ranging from 10 to 22 m/s and max accelerations ranging from 2 g to 9 g. Based on curvature analysis of flight path, bats were further grouped into those that exhibited straight versus curved flight paths. For straight paths, bats shortened pulse duration and increased the frequency of calls

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as they approached the roost, whereas bats flying in curved paths demonstrated no overall change in acoustic signals. Furthermore, bats consistently produced calls at intervals above the time limit of call-echo overlap. Our results demonstrate that during high-speed flight, bats rely on their echoic stream to dynamically guide flight behavior.

BSP-6-4 Klompen, AML*; Kayal, E; Collins, AG; Cartwright, P; University of Kansas, Station Biologique, Roscoff, France, Smithsonian Institution, Washington, DC; *annaklompen@ku.edu*

Why are box jellyfish so toxic? Phylogenetic and selection analysis of an expanded family of putatively pore-forming jellyfish toxins across medusozoans (Cnidaria: Medusozoa)

Box jellyfish (Class Cubozoa) are known for being particularly dangerous to humans due to exceptionally potent venoms, which is attributed to the presence and abundance of a cnidarian specific pore-forming toxin family called jellyfish toxins (JFTs). These highly hemolytic and cardiotoxic components have previously been reported in species outside of Cubozoa, but no formal analysis of JFT distribution across the cnidarian subphylum Medusozoa has been conducted. We present a thorough annotation of JFTs from 143 publicly available cnidarian transcriptomes and document 109 putative JFTs within over 20 medusozoan species. Phylogenetic analyses show that JFTs form two distinct clades, called JFT-1 and JFT-2. JFT-1 includes all previously characterized cubozoan JFTs as well as representatives from Hydrozoa (hydra, hydromedusae) and Scyphozoa (true jellyfish). JFT-2 is primarily composed of hydrozoan toxins of unknown function. Using selection analyses, we found that a subset of cubozoan JFT-1 sequences are influenced by gene-wide positive episodic selection when compared to JFT-1 toxins from other taxonomic groups, suggesting duplication followed by subfunctionalization as a potential mechanism for the increased venom potency within cubozoans, possibly driven by a dietary shift to vertebrates. Additionally, using published RNA-seq data we found that JFTs are expressed in developing or mature medusae in several species as well as the prey-capture polyps of a colonial hydrozoan. Overall, our findings show a complex evolutionary history of JFTs involving duplication and functional diversification that likely

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resulted in highly toxic cubozoan venoms, and consequently dangerous envenomation of humans.

101-3 Knight, QK*; Viteri, M; Hill, A; Hadly, E; Spelman College, Stanford University; *qknight@spelman.edu*

Modeling the response of California coastal sage scrub to over a century of climate change

California coastal sage scrub (CSS) supports a multitude of native plant and animal species in the coastal range of central and southern California. CSS distribution has been reduced to an estimated 10% of its original extent since historical times. Previous studies have shown that climatic variables such as temperature and precipitation strongly influence CSS distribution. We here parse out the respective roles that climate and human development have played in determining CSS's current distribution using species distribution modeling (SDM). We also determine how future climatic change will influence the distribution of CSS. To answer these questions, we identified the historical distribution of CSS in California using data from the 1930's Weislander Vegetation Survey, determined its preferred climatic niche based on 9 climatic variables, and projected the resulting SDM into today's climatic regime. Next, we mapped on modern (2010's) observations of CSS using the U.S. Forest Service's CALVEG vegetation data to compare CSS's estimated preferred range to its actual current distribution. Using our SDM, we then predicted how the modern range of CSS would change by 2050 using CMIP climate projections. We found that the climatic envelope of CSS remained relatively stable when projected from a historical baseline into both the present and future. This indicates that climate change may be less important in determining the niche of the CSS community than previously thought. This discrepancy may be a result of land use change over recent history. Modeling the niche of CSS reveals the influence that human impact and climate change will have on a threatened ecosystem.

8-6 Ko, D*; Haddad, A; Clopath, C; Lin, H-T; Imperial College London; *dsk13@ic.ac.uk*

Simultaneous neural encoding of spatial and directional information in the dragonfly

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Dragonflies use their acute vision to detect and track prey before taking off for an aerial interception. Due to the limited bandwidth available in the ventral nerve cord of the dragonfly, the rich visual information acquired in the hunt scenario must be reduced to a critical set of parameters that encode the most relevant target information. A set of 16 visually responsive neurons called Target Selective Descending Neurons (TSDNs) run through the neck connective, bridging the brain to the motor centres of the dragonfly. These cells have been shown to strongly select prey movement direction in large spatial receptive fields. A population vector coding has been suggested as a potential encoding mechanism for the prey directionality, and yet information theory predicts that TSDNs encode both direction and position information. Using newly recorded high-resolution receptive fields, we explore a unifying model that accounts for the spatial-directional encoding, and their coupling. This work highlights the efficient information encoding in an insect neural circuit and reveals how visual information might be used for a complex behaviour such as aerial interception.

90-6 Kobiela, ME*; Zambre, A; Snell-Rood, EC; Agrawal, AA; University of Nebraska, Lincoln, University of Minnesota, Twin Cities, Cornell University; *megan.kobiela@unl.edu*

Effect of anthropogenic sodium on chemical defense and coloration in monarch butterflies

The monarch butterfly *Danaus plexippus* is a textbook example of a toxic animal with aposematic coloration, but we know little about how anthropogenic stressors may affect their chemical defense (cardenolides) or wing color. Given the interest in using roadside habitat to conserve monarchs and pollinators, we chose sodium as a representative anthropogenic stressor since it is often elevated along roads due to application of deicing salt. We reared monarch caterpillars through adulthood on common milkweed *Asclepias syriaca* watered with a salt solution to mimic sodium levels commonly found along roads in Minnesota, USA. We quantified the concentration and relative polarity of cardenolides in milkweed and in the wings of 100 female monarchs using HPLC. We also measured the hue, saturation, and brightness of an orange section on the forewings of 100 male and female monarchs. Preliminary results show

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no significant difference in total cardenolide concentration between control and treatment milkweed or monarchs. However, we found differences in the concentrations of specific cardenolides sequestered by monarchs in the two groups - monarchs fed salted milkweed had higher concentrations of more non-polar cardenolides, which are typically more toxic than polar cardenolides. While the fitness impacts of this change are unclear, these results emphasize the importance of considering all aspects of an organism's biology when making conservation decisions.

62-12 Koch, RW*; Shannon, RP; Detwiler, JT; Bolek, MG; Oklahoma State University, Stillwater, OK, USA, University of Manitoba, Winnipeg, MB, Canada; *ryan.koch@okstate.edu*

Molecular identification of juvenile Neoechinorhynchus spp. (phylum: Acanthocephala) infecting ostracod and snail hosts provides insight into acanthocephalan host use

The role of invertebrate hosts in some acanthocephalan life cycles is unclear because juveniles are difficult to identify to species using morphology. The turtle acanthocephalan, *Neoechinorhynchus emydis*, has been reported in ostracod and snail hosts. However, the role these hosts play in the life cycle is unknown. To better elucidate the role of ostracods and snails, we collected 558 snails of 2 species and 37,208 ostracods of 4 species in Oklahoma and examined them for infections. Juvenile acanthocephalans were morphologically and molecularly characterized, using the ITS region of parasite rDNA. We also sampled turtle definitive hosts to compare sequences of adult to juvenile acanthocephalans. Of the 23 locations sampled for snails, 7 (30%) were positive for juvenile acanthocephalans. Overall prevalence of acanthocephalans in the snails *Planorbella trivolvis* and *Physa acuta* was 20% and 2%, respectively. In contrast, only 1 species of ostracod (*Physocypria* sp. morphotype 1) was infected, with an overall prevalence of 0.1%. Although 4 species of acanthocephalans infected turtle definitive hosts, all the ITS sequences from juveniles infecting snail hosts were conspecific with *N. emydis*. In contrast, the ITS sequences from juvenile acanthocephalans from ostracods were conspecific with 2 species of acanthocephalans from turtles, *N. emydis* and *N. pseudemydis*, and 1 species of acanthocephalan from fish (*N. cylindratus*). These results indicate

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that *N. emydis* commonly infects freshwater snails, whereas other species of *Neoechinorhynchus* appear not to infect snail hosts.

70-1 Koehl, MAR*; Silk, WK; University of California, Berkeley, University of California, Davis; *cnidaria@berkeley.edu*

How kelp in drag lose their ruffles: Environmental cues, growth kinematics, and mechanical constraints

Many biological structures are curved. Here we use a Lagrangian analysis of growth (following tissue elements to determine how their expansions and growth displacements change as a function of time and position) to reveal how spatio-temporal patterns of growth can set up mechanical stresses that drive the production of ruffles in a biological structure in response to environmental.cues. *Nereocystis luetkeana* , abundant nearshore kelp, have wide ruffled blades that minimize self-shading in slow flow, but narrow flat blades that reduce hydrodynamic drag in rapid flow. Previously we showed that blade ruffling is a plastic trait associated with a transverse gradient in longitudinal growth. Here we consider both expansion of tissue elements and their displacements due to growth in blades and find that growth patterns regulating ruffle formation are induced by tensile stress due to hydrodynamic drag, but not by shading or nutrient levels. When longitudinal stress in a blade is low in slow flow, blade edges grow faster than the midline in young tissue near the blade base. Tissue elements are displaced distally by expansion of younger proximal tissue. As predicted by elasticity theory, strain energy caused by the transverse gradient in longitudinal growth is not released by elastic buckling until the blade grows wide and thin enough, producing ruffles distal to the region where the growth inhomogeneity was initiated. If a blade experiences higher stress in rapid flow, edges and midline grow at the same rate, so the blade becomes flat as these new tissue elements are displaced distally.

BSP-11-1 Koeller, KL; University of Florida, Gainesville, Florida; *kkoeller3115@gmail.com*

Limbs, shoulders, necks, and trunks: A search for the neck-trunk

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boundary in snakes using a comparative anatomical study of legless lizards

At least 26 lineages of snakes and lizards have independently evolved the elongate, limbless body plan most well known in snakes. Elongation is always a feature in this transition and precedes limb loss, yet which body regions contribute most to elongation has been difficult to discern. This is largely because in elongate species, there is a breakdown in the boundary between the neck and trunk regions. In limbed species, this boundary is defined by the location of the sternum, and there are certain features that all occur at this boundary (e.g. limbs, vertebral characters). But many elongate species lack limbs and even sterna, and other neck-trunk boundary characters become displaced relative to each other during the evolution of limblessness. This has caused confusion about where the neck-trunk boundary is in elongate species, as it is difficult to determine what character should define the boundary when limbs and sterna are absent. To bring clarity to this issue, CT data from limbless taxa across Squamata and closely related outgroups were examined to determine the axial positions of various neck-trunk boundary markers such as the pectoral girdle, the posterior extent of cervical vertebral characters, and overall vertebral shape as determined by a geometric morphometric analysis. Results suggest that, generally, the position of the pectoral girdle is the most conserved, and cervical characters such as hypapophyses are the most posteriorly displaced, compared to the plesiomorphic body plan. In elongate species with highly reduced pectoral girdles, the boundary as determined by any vertebral character does not coincide with the position of the pectoral girdle, meaning vertebral characters may not be a reliable indicator of where the traditionally defined neck-trunk boundary would have been in species without pectoral elements.

34-1 Komilian, K*; Ko, H; Waters, J; Hu, D; Georgia Institute of Technology, Providence College; *keyana5@gatech.edu*

Metabolism of small groups of fire ants workers scale isometrically

For both single organisms and social insect colonies, metabolic rate per mass decreases as the total mass increases, suggesting that cooperation can reduce energy use. However, it is unknown

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whether this benefit pertains to segments of insect colonies. In this study, we perform experiments to measure the scaling of metabolic rates in 20 - 800 fire ant workers. We measure the carbon dioxide production rate of varying masses of ants in containers of fixed size as a function of temperature and dry or wet conditions. Surprisingly, we found that in all cases, the metabolic rate scales simply with the number of ants, and that fire ant workers do not expend less energy per capita while in larger groups.

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1-9 Korpach, AM*; Garroway, CJ; Mills, AM; von Zuben, V; Davy, CM; Fraser, KC; University of Manitoba, Winnipeg, MB, York University, Toronto, ON, Ontario Ministry of Natural Resources and Forestry, Peterborough, ON; *alicia_korpach@hotmail.com*

Finding dark routes: A migrating nocturnal bird avoids artificial light during both travel and stopovers

Flying animals use aerial habitats to forage, communicate, and travel, and anything that fragments that habitat may limit their ability to use airspace efficiently. As artificial light at night continues to grow, nocturnally migrating birds increasingly encounter airscapes fragmented by light. Attraction to bright lights by groups of nocturnal migrants is well documented, but there is also evidence of light avoidance, particularly during stopovers. We do not have a clear understanding of how birds that do not travel in groups, and nocturnal species specifically, perceive and navigate artificial light along their full migratory paths. We investigated potential selection or avoidance of artificial light during migration in a highly nocturnal species, the Eastern Whip-poor-will (*Antrostomus vociferous*). We GPS-tracked birds on their southbound migrations through eastern North America, and compared their routes with artificial light, dark-sky connectivity, and terrestrial connectivity surfaces in a resource selection framework. The degree of connectivity of dark skies was the best predictor of Whip-poor-will routes, and stopovers occurred almost exclusively in dark, rural areas. These dark-sky preferences were detected in analyses at various spatial scales, providing evidence for avoidance of, rather than attraction to, artificial light. The presence and connectivity of an aerial resource, dark skies, influenced movements of this nocturnal species, and our findings may apply to other aerial migrants that use dark skies.

15-6 Kortekaas, K*; Jean-Joseph, HG; Kotrschal, K; Dept. of Behavioral and Cognitive Biology, Univ. of Vienna, Vienna, Austria & Wolf Science Center, Domestication Lab, Konrad-Lorenz Institute of Ethology, Univ. of Veterinary Medicine, Vienna, Austria ; *kim.kortekaas@wolfscience.at*

Social context influences resting physiology in wolves and dogs

Due to domestication, it has been suggested that the social orientation of wolves on their pack makes has been shifted towards humans in dogs, potentially causing dogs to be more alert to their environment than wolves. Indeed, previous results show that dogs resting isolated of their pack members and with an unfamiliar human around were more alert than wolves in the same condition - alertness was defined as degree of activation along the sleep-wake continuum and measured via cardiac parameters. To test the influence of social context on alertness, we replicated this study comparing wolves and dogs in two states of activation: (1) inactive wakefulness and (2) resting, and in three conditions: (1) subject is alone, (2) subject is with a familiar human partner, (3) subject is with pack members. We found that wolves and dogs were more alert when resting alone than with pack members. When dogs were resting with a familiar human around they were less alert than wolves, but not when awake. We conclude that alertness in wolves and dogs depends on social context, i.e. domestication has probably partly shifted the social orientation in dogs from pack members to humans, which could make them more flexible in their response to their environment than wolves.

S11-11 Koster, JM; University of Cincinnati; *jeremy.koster@uc.edu*

Broadening the scope of canine science: The dogs of the Nicaraguan forest

As the world's most ubiquitous carnivore and the first domesticated animal, dogs have spurred the emergence of a unique interdisciplinary field of research: Canine Science. Relatively few researchers, however, study dogs and their relationships to humans outside of the familiar contexts of industrialized societies. As an anthropologist, I work among indigenous Nicaraguans, whose dogs serve as hunting companions and watchdogs. These dogs receive

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virtually no veterinary care. They are undernourished, subsisting largely on rice and bananas. Mortality is relatively high at all ages, and few dogs live past six years old. Some dogs, though, provide substantial value as hunting companions, helping their owners acquire large quantities of hunted game. In this environment, the main advantage of dogs is that they boost encounter rates with several key prey species. Dogs are a hindrance when hunting other species, though, implying that dogs are not universally beneficial hunting accessories. From a conservationist perspective, dogs may be worthwhile alternatives in settings where projectile weapons can otherwise be used to target slow-breeding and vulnerable species, such as primates. Dogs may also be vectors of diseases to wildlife populations, however, and the Nicaraguan dogs show high rates of canine distemper virus and parvovirus that could be transmitted to vulnerable feline species. Ongoing work is assessing the survivorship of dog populations as a function of their utility as hunting companions. In general, this population provides a diverse empirical counterpoint to a canine science that has examined few dogs in subsistence-oriented contexts.

76-4 Kouete, MT*; Bletz, MC; LaBumbard, B; Woodhams, DC; Blackburn, DC; University of Florida, UMass; *tallakmarcelk@gmail.com*

Parental care drives microbiome transmission in oviparous skin-feeding caecilians

Parental care encompasses multiple forms of care and behaviors by parents to enhance the fitness and survival of offspring. Among vertebrates, amphibians are well known for their diverse forms of parental care which include elaborate ways to prevent desiccation of eggs and juveniles. One of the most extreme forms of parental care occurs in oviparous species of the wormlike burrowing amphibians, the caecilians. Some oviparous caecilians are believed to spend up to three months attending eggs and providing care to juveniles after they hatch. During this time the attending female provides its skin to the attended juveniles to feed on, a phenomenon known as dermatophagy. The female's skin is rich in lipids and provides nutrients to the developing juveniles, but whether the skin might also transfer a microbial flora remains unknown. Here, we investigated the skin and gut microbiomes of mothers and juveniles in *Herpele squalostoma* to evaluate the

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possibility of transfer of microbes. We obtained skin and gut microbiome samples from wild caught caecilians at different life stages and reproductive status. We followed the Earth Microbiome Project protocols to extract genomic DNA and amplify the V4 region of the 16S rRNA, conducted sequencing on the illumina MiSeq platform and processed microbiome reads in QIIME2. We characterize the skin and gut microbiome community of *H. squalostoma* in relation to parental care and provide the relationships between bacteria prevalence and abundance between attending females and their juveniles. Our results indicate that both microbial prevalence and abundance are highly conserved on the skin and in the gut between attending females and juveniles. When considering the most abundant bacteria in our dataset, the skin and gut of both attending females and their juveniles contained similar phyla in comparable proportions.

62-13 Kramp, R*; Rudzki, E; Kohl, K; Stephenson, J; University of Pittsburgh; *rachael.kramp@pitt.edu*

Examining skin microbiome of Trinidadian guppy and ectoparasite infection dynamics

The epidermal mucus layer has established importance to fish systems, but there is an evident gap in knowledge of the microbial community's structure and function ('microbiome') inhabiting fish skin, particularly in freshwater. In general, we know that the microbiome of other are organs, such as the gut, are essential to host health and provide protection from parasites by priming the immune system before invasion. Like gut microbiomes, the skin microbiome contains mutualistic and commensal microbes adapted to the epidermal surface, and these are affected by environmental and host species-dependent factors. We tested whether the microbiome present on the host pre-infection could predict subsequent infection susceptibility to an ectoparasitic helminth. Using 16S rRNA analysis, we studied the bacterial communities of Trinidadian guppies (*Poecilia reticulata*) and their interaction with *Gyrodactylus turnbulli*. *Gyrodactylus* parasites are ubiquitous monogenean ectoparasites that infect the skin and gills of teleost fish in marine and freshwater ecosystems. We swabbed fish skin to inventory the skin microbiome before experimentally infecting them with *G. turnbulli*. We found that fish skin microbiome communities

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can predict infection severity. Additionally, we found that male and female guppies differed in their alpha diversity before infection with *G. turnbulli*, their defense against the parasites, and their behavior. **Our results, therefore, suggest that the fish skin microbiome alters the host-parasite interactions during *Gyrodactylus* infection, ultimately changing parasite load, thus presumably mortality and transmission.** Future experiments will test how environmental factors may alter the skin microbiome, improve or worsen infection outcomes for the host, and how parasites may respond to changing microbial communities.

34-4 Kraskura, K*; Jerde, CL; Eliason, EJ; University of California, Santa Barbara; *kkraskura@ucsb.edu*

Active and resting metabolic rate scaling relationships in fishes across ecologies, salinity, and body shapes

Metabolic scaling with allometric exponents (0.66 < *b* < 1) is a well-recognized phenomenon across all living systems and providing the cornerstone for the metabolic theory of ecology. Metabolic scaling relationships connect individual physiology to broad scale ecology, and are incorporated in multi-scale bioenergetics research to support academic and applied science. Whether the scaling exponent is *universal* is hotly debated as many continue to identify variation in metabolic scaling relationships. Contextual sources of variation include, taxonomic groups, ecological roles and lifestyles, and environmental conditions. Individual activity level (active vs resting state) also changes metabolic scaling: active metabolic rates (AMR) are predicted to scale with exponents b_{AMR} ~ 1, and resting metabolic rates (RMR) with $b_{RMR} < 1$. However, it is largely unknown how AMR scales across different contexts, and how b_{AMR} and b_{RMR} relate within these contexts. We explored and compared the variation in scaling of AMR and RMR in fishes with different body shapes and ecologies. Contrary to predictions, we found lower scaling exponent for AMR than RMR ($b_{AMR} < b_{RMR}$) in fish taxa. Further, we found different scaling relationships of AMR and RMR for demersal and reef-associated fish, short-deep and fusiform shaped fish, temperate and tropical fish, salt and freshwater fish. And we found no evidence for consistent relationships between context-specific scaling of RMR and AMR (all associations were observed: $b_{AMR} > b_{RMR}$, $b_{AMR} < b_{RMR}$, $b_{AMR} \sim b_{RMR}$). As signified by our

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results, it is important to consider both, the metabolic state (active and resisting) and life-history characteristics, to ensure robust inference about changing metabolism-dependent biological processes.

32-8 Kriefall, NG*; Rippe, JP; Castillo, KD; Davies, SW; Boston University, UT Austin, UNC Chapel Hill; *nicfall@bu.edu*

Testing the resilience of coral microbial networks to disturbance

Microorganisms can provide essential services for their host organisms, and this is especially true for communities of algal symbionts and bacteria hosted by tropical corals. These microbes can interact with the host and with each other through nutrient and metabolic byproduct exchange and can form complex co-occurrence networks, with important implications for coral resilience. It is well-established that these symbiosis networks are easily perturbed by changes in temperature, however the influence of multi-variable storm disturbance events on the resilience of these microbial networks remains largely unexplored. Here we show that key metrics of bacterial networks hosted by the coral *Siderastrea siderea* were disrupted by the passage of a category 5 hurricane (Irma), but showed evidence of recovery after one year. Namely, the composition of bacterial families most central to these networks was more similar before and one year after the disturbance when compared to immediately after disturbance. Similarly, network cohesion (measure of connectedness) was lowest immediately following disturbance when compared to before and after the storm. These same network analyses are being explored in coral-associated algal symbiont communities and network resilience across three inshore-offshore transects will be contrasted, as inshore corals in the Florida Keys have previously exhibited increased resistance to environmental stressors relative to their offshore counterparts. These initial results indicate that storm disturbances substantially impact coral-associated bacterial networks, which may disrupt microbial functions provided to their hosts. This study explores the role microbial partners play in coral resilience in the face of severe storm disturbance events, which are projected to intensify over the coming century.

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56-10 Krishnan, K; Gurka, R*; Coastal Carolina University; *rgurka@coastal.edu*

Aerodynamics and energetics of raptors: a comparative analysis between an owl and a hawk

The aerodynamics and energetics of two large raptors are studied experimentally in free forward flight mode. A great horned owl and a Harris's hawk were trained to fly in a wind tunnel. A perch-to-perch flight was chosen and multiple flights were conducted. The velocity fields behind the flapping wing of the birds were sampled around the midspan location using time-resolved PIV and the birds' kinematics were measured using high-speed imaging, simultaneously. From the velocity fields, the lift and drag coefficients have been estimated using the momentum equations. Results show that the lift and drag characteristics of the two birds vary significantly. The owl exhibits higher lift variations over the wingbeat cycle compared to the hawk. These variations are essential for weight support while flying at low speeds. The hawk drag coefficient was ~2 times lower than the owl as the hawk is a high-speed flier. While the steady drag of the owl is positive throughout the wingbeat, negative values over the wingbeat cycle have been observed for the hawk, indicative of efficient flapping mode. Using the experimental data, the energy requirements during flight were estimated for two cases: i) aerodynamic power output during flapping flight and ii) power expenditure in intermittent flight. The owl was 30% heavier and its flight speed owas 20% lower than the hawk. Results show that the aerodynamic power output of the owl is higher than the hawk over the wingbeat cycle. But the estimated specific-power and work done by the flight muscles are lower for the owl. Power expenditure results show that the intermittent flight pattern yields moderate saving of aerodynamic energy requirements and minimizes the total power output for both birds. Yet, the results of the owl show relatively higher benefits from the intermittent flight.

87-5 Kuhn, BF*; Rößner, GE; University of Johannesburg, Bayerische Staatssammlung für Paläontologie und Geologie; *kuhnbf@gmail.com*

Large bodied Felidae from Pakistan

A trip to the Bayerische Staatssammlung für Paläontologie und Geologie in München (Munich) Germany in 2018 revealed a set of

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fossils originally discovered in 1955 from the Chinji-Formation, of Northern Pakistan and in 1956 from the Dhok Pathan, Latewali Bhan, Dhok-Pathan-Formation, Northern Pakistan. A total of thirteen specimens were found analysed and photographed. Museum specimens include, but were not limited to, numbers 7255, 7358, 2011, 2636, 2772, 2773, 2774, 2775, 2776, 2777, 2778, 2779 and 2780. All of the specimens appear to be that of large bodied Felidae, some have original identifications as Carnivora while others are listed as Panthera leo spelaea and two were originally identified as Suidae. All of said specimens are either dental or pedes. Original identifications are noted where available and changes to identifications over time and by whom are noted as well. Material is compared to published Machairodont specimens and unpublished Machairodus material from Miocene sites in Spain. We include comparisons to recently discovered Pleistocene 'lions' from southern Africa as well as specimens of Panthera spelaea from the cave locations of Châtaeu and Azé, France. Here we compare identified species to published lists from the locations and discuss relationships to the chronology of the sites.

79-7 Kuruvilla, M*; Berdahl, A; Dell, A; Knouft, J; University of Washington, National Great Rivers Research and Education Center, Saint Louis University; *mariakur@uw.edu*

Effect of temperature and group size on the collective response of fish to a threat

Ectothermic animals, such as fish, are more vulnerable to fluctuations in water temperature than endothermic predators such as bears or humans. This asymmetry in the effect of environmental conditions on behavior can influence predator prey interactions. In order to investigate whether fish are able to compensate for their harsh environment by using social information, we recorded the swimming and response to loom stimulus of golden shiners (*Notemigonus crysoleucas*) of different group sizes. Group sizes varied from 1 to 32 fish and the water temperature varied from 9&degC to 29&degC. Using computer vision and tracking software, idtracker.ai, we analyzed the trajectories of every individual. We see that the speed and acceleration of the fish to respond to the stimulus increase with increase in temperature and decrease with increase in group size. Latency to respond to the stimulus

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decreases with increase in temperature as well as group size. Distance to the center of the tank decreases with increase in temperature. Average nearest neighbor distance also decreased with increase in group size which suggests that the fish were schooling more tightly in bigger group sizes.

79-4 Kusaka, C*; Valdivia, J; Erell
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Methods of estimating lizard space use: a comparison of methods across species, sex, and age classes

Home range is an important concept in animal ecology but there are multiple methods available for assessing home ranges and insufficient clarity on when to use which estimation method. We applied the two most common methods, kernel utilization distribution and minimum convex polygons (MCP), in field studies examining multiple lizard species and demographic groups to determine whether the methods produce similar results, and to assess the efficacy of focal observations in estimating home range size. We collected data through 1 h focal observations in Oregon on adult Long-nosed leopard lizards (Gambelia wislizenii) and Western whiptails (Aspidoscelis tigris) and in Colorado on adult and juvenile Colorado checkered whiptails (A. neotesselata). Our observation data were supplemented with location data obtained through surveys to obtain resightings, and then we evaluated home range estimates using observation locations alone compared to observation and resighting data combined. Our findings revealed that total home range estimations were significantly larger, often by a factor of 2, when applying the kernel utilization distribution compared to the MCP method. The methods reveal differences in strategies of space use based on species, sex and age class. Furthermore, altering the bandwidth of the kernel utilization distribution to fit the home range estimate given by MCP can provide insight into the probability density estimates. We conclude that the results of a home range analysis reflect an interaction between the estimation method applied, and the age, sex, and species examined, and that short duration focal observations can provide vital information on space use.

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38-5 Kyomen, SM*; Simon, MN; Kohlsdorf, T; University of Sao Paulo; *stella.kyomen@hotmail.com*

Modular architecture in lizard autopodia: Relationships with microhabitat usage in Tropiduridae (Squamata)

A ubiquitous feature of phenotypes is the modular architecture of composing traits. Modularity expresses the organization of phenotypic elements into modules that comprise high integration among components that likely share developmental pathways or execute integrated functions, in contrast to a lower correlation between components of different modules. The tetrapod autopodium is an excellent system to explore modularity, as it has been deeply studied under functional, developmental and ecological approaches. In lizards, increased palmar surface area and elongated Digit IV are interpreted as important for locomotion in sand in some species of the Tropiduridae. Our hypothesis is that colonization of sandy environments by Tropiduridae lizards affected the intensity of phenotypic integration among digit elements in the autopodium. Using X-ray and imaging software, we measured the length of individual phalanges, metacarpals and metatarsals in forelimbs *(manus)* and hindlimbs *(pes)* of six species in Tropiduridae. Our morphological database comprises 17 linear measurements in *manus* and 19 linear measurements in *pes*. Results provided correlation coefficients near 0.8 comprising the digit elements in both limbs, indicating that the autopodium is highly integrated. The comparison test between empiric and theoretical matrices in *Tropidurus catalanensis* showed evidence for two modules in *pes*: one comprising proximal phalanges and metatarsal elements and another encompassing distal phalanges in all five digits. Results likely indicate functional and developmental relationships among osteological elements, justifying the use of tropidurid lizards as a model and promoting unique insights about how osteological elements are integrated throughout ontogeny.

21-9 Lacy, B*; Rivera, M; Estrada, L; Rahman, M; University of Texas Rio Grande Valley, Brownsville, TX; *Michelle.rivera02@utrgv.edu*

The ramifications of prolonged co-exposure to heat and pesticide conglomerate in swimming behaviors of common goldfish (Carassius auratus)

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We are currently experiencing rapid growth in pollutants defiling our freshwater environment. The main contributors to the disruption are anthropogenic activities, such as agriculture and city pest control, increasing the amount of chemical contamination. This includes pesticides (more aptly called biocides) that contribute to stressors debasing aquatic ecosystems. Heat stress (through global climate change, heat waves, or natural seasonal variation) also negatively influences the behavior of aquatic animals. In this study, we examined dose-dependent and time-dependent effects of pesticide cocktail (metalachlor, linuron, isoproturon, tebucanazole, aclonifen, atrazine, pendimethalin, and azinphos-methyl) and heat stress (32° C for 1-month exposure) on the free-swimming behavior and cumulative actionless time (resting time) of goldfish (Carassius auratus, a model teleost species). Behavioral analysis showed an inverse relationship between distance swam and cumulative actionless time, with a dose-dependent, time-dependent, decrease in distance swam as well as a dose-dependent, time-dependent increase in cumulative actionless time. Collectively, these results indicate that the combined effects of heat and pesticide stress alter behavior and negatively impact natural swimming patterns in teleost species, such as Carassius auratus.

90-9 Lacy, B*; Rivera, M; Rahman, MS; Rahman, MS; University of Texas Rio Grande Valley, Brownsville TX; *brittney.lacy01@utrgv.edu*
Environmentally relevant pesticide cocktail and heat stress co-exposure affect osmoregulation and antioxidant system of goldfish gill and kidney
Aquatic ecosystems are becoming increasingly inundated by noxious chemicals, such as pesticides, through human activities. These chemicals combined with other stressors like heat stress create volatile environments that negatively affect the physiological functions of aquatic organisms. Through this research, we observed the dose-dependent effects of pesticide cocktail (metalachlor, linuron, isoproturon, tebucanazole, aclonifen, atrazine, pendimethalin, azinphos-methyl for 1-month exposure) combined with elevated temperatures (32° C for 1-month exposure) on morphology of gills and kidneys, and expression of catalase (CAT, an antioxidant), superoxidase dismutase (SOD, an antioxidant), and renin in kidney tissues of goldfish (Carasius auratus, a model

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teleost species). Histopathological analysis showed wide-spread damage to both gill and kidney tissues in higher temperature and pesticide co-exposure groups, including extensive fusion of secondary lamellae, club-shaped primary lamellae, rupture of epithelial layer, loss of normal architecture, glomerular shrinkage, hemorrhaging, and degeneration of tubular epithelium. Immunohistochemical analysis demonstrated a change in CAT and SOD expressions in kidney tissues in combined exposure to pesticide and higher temperature compared to control (22° C). Expression of renin in kidney tissues was also altered with varying doses of pesticides and elevated temperature. Collectively, our results suggest that the combined effects of heat stress and pesticides cause cellular damages, as well as down-regulate the osmoregulatory and antioxidant enzyme activities in gill and kidney tissues of common goldfish.

81-7 Laforest, KV; Peele, EE*; Yopak, KE; University of North Carolina Wilmington; *eep5093@uncw.edu*

Older and Wiser? Ontogenetic shifts in brain size and brain organization in the Atlantic sharpnose shark, Rhizoprionodon terraevovae

Throughout an animal's life, species may occupy different environments and exhibit distinct life stages, known as ontogenetic shifts. Life histories of most cartilaginous fishes are characterized by these ontogenetic shifts, defined by changes in habitat and diet, as well as behavioral changes at the onset of sexual maturity. In addition, cartilaginous fishes experience indeterminate growth, whereby both the brain and body grow continually throughout their lives. Despite lifelong neurogenesis in these species, little work has been done on ontogenetic changes in brain size or brain organization, which may be informative about functional shifts in sensory and behavioral specializations. This study quantified ontogenetic changes in brain-body scaling and the scaling of seven major brain regions in 35 specimens of the Atlantic sharpnose shark, *Rhizoprionodon terraenovae*, at all stages of maturity. Relative brain size increased significantly with body mass throughout ontogeny in this species, and the telencephalon, diencephalon, optic tectum, and medulla oblonga scaled with negative allometry against brain mass. However, notably, the

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olfactory bulbs and cerebellum scaled hyperallometrically to the rest of the brain, whereby these structures enlarged disproportionately as this species matured. Changes in the relative size of the olfactory bulbs throughout ontogeny may reflect an increased reliance on olfaction at later life history stages, while changes in the relative size of the cerebellum throughout ontogeny may be indicative of the ability to capture faster prey or an increase in migratory behavior as this species moves to offshore habitats, associated with the onset of sexual maturity.

S3-11 Laidre, ME; Dartmouth College; *mark.laidre@dartmouth.edu*
From Behavior to Architecture and Back: the Evolution of Social ('so-shell') Life in Social Hermit Crabs
Architecture and social behavior might appear to occupy different worlds: one the physical world, the other the social world. Yet for many animals these two worlds are intimately connected, having reciprocally shaped one another over ecological and evolutionary time. The connection between architecture and animal social behavior is perhaps nowhere more intimate than among social hermit crabs (Coenobita compressus), which have evolved to occupy architecturally remodeled shells and which must navigate a shell housing market requiring substantial social interaction with conspecifics. Here I review over a decade of experimental work on this system. I focus on the dynamic feedback between behavior and architecture, particularly the ways that behavior shapes architecture and the ways that architecture in turn shapes behavior. I highlight the fundamental importance of studying physical mechanisms of behavior, which in the social hermit crab system has involved fusing experiments on social behavior with detailed analyses of shell architecture, often through interdisciplinary collaborations with engineers, morphologists, and biomechanists. Altogether, these studies have incorporated diverse approaches that span field and laboratory, and underscore the significance of studying architecture to fully understand the evolution of social life. Based on these long-term studies of social ('so-shell') life in social hermit crabs, I conclude with a broader conceptual framework, which outlines the scope for studying dynamic feedbacks between architecture and animal social behavior across a wide variety of systems. With this approach, scientists

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can ultimately deduce general principles of how and why architecture shapes social behavior and vice versa.

26-4 Lam , EK*; Torres-Velarde, JM; Allen, KN; Crocker , DE; Vazquez-Medina, JP; University of California, Berkeley, Sonoma State University; *emily_lam@berkeley.edu*
Direct reprogramming of dermal fibroblasts derived from Northern elephant seals into muscle cells
""Ex vivo"" tissue culture allows the study of complex cellular mechanisms that are relevant to physiological responses in animals while overcoming the challenges presented by studying animals that are not tractable. In a primary cell culture system, certain proliferating cells can be functionally reprogrammed into other cell types via overexpression of key genes. Dermal fibroblasts can be reprogrammed into muscle progenitor cells (myoblasts), which are often challenging to obtain but offer a unique system to study metabolic responses, by overexpression of the myogenic transcription factor myod. We isolated fibroblasts from Northern elephant seal (NES) skin samples and propagated them in primary culture. We overexpressed myod in NES fibroblasts and conducted antibiotic selection with 2 ug/mL puromycin for 3 days. As expected, expression of myod was significantly higher in transfected cells according to qPCR analysis (t-test $p < 0.05$). Treatment with small molecules (CHIR99021, Forskolin and Repsox) enhanced myod expression. Furthermore, fibroblasts overexpressing myod expressed downstream markers of myogenesis (myogenin, myosin heavy chain 1 and myosin heavy chain 8) and the effect was enhanced when myod-overexpressing cells were supplemented with small molecules. We are currently evaluating the capacity of myod-overexpressing dermal fibroblasts to differentiate into myotubes and comparing metabolic profiles with primary NES myoblasts. Establishing differentiated muscle fibers from other mature cell types could provide a unique platform to conduct mechanistic studies in species where muscle tissue samples cannot be obtained from live animals.

S10-3 Lamont, EI*; Emlet, RB; University of Washington, Seattle, WA, University of Oregon, OIMB, Charleston, OR; *elamont@uw.edu*

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The swimming kinematics of barnacle cyprid larvae using permanently fused setules

Thoracican barnacles undergo several planktonic larval stages before settlement and metamorphosis. The final stage is the cyprid, a non-feeding larva with six pairs of swimming thoracic appendages and two anterior antennules used for attachment during settlement. Extensive research has focused on the behavior of cyprid antennules; however, there is limited knowledge on the pre-settlement swimming behavior of cyprids. Here, we used high speed videography to observe cyprids of the barnacle *Balanus glandula* and describe thoracic appendage swimming kinematics. Cyprids use a drag-based method of swimming, with their six pairs of thoracic appendages undergoing metachronal power strokes and synchronous recovery strokes. During the power stroke, plumose setae on each appendage pair spread laterally into a high surface area and high drag paddle shape composed of a meshwork of permanently fused setules. This interconnected setal array collapses into a low surface area and low drag shape during the recovery stroke. Cyprids of *B. glandula* swim upwards at an average speed of 1.4 cm/sec (about 25 body lengths/sec) and can reach an instantaneous velocity of up to 6 cm/sec. At their average speed, cyprids move at the intermediate Reynolds number of 10, in which both viscous and inertial forces affect movement. Cyprids change their swimming direction by beating their versatile thoracic appendages synchronously through the power stroke and angling their posterior-most appendage pair to likely act as a rudder to alter direction of motion. These descriptions greatly enhance our understanding both of cyprid motility and of how these small plankton can use multiple appendages with recently-discovered fused setule arrays to reach high swimming speeds.

32-7 Lane, A*; Benayahu, Y; McFadden, CS; Harvey Mudd College, Claremont CA, Tel Aviv University, Tel Aviv ; *alane@g.hmc.edu*

Biogeography of soft corals in the Indo-Pacific assessed using DNA barcodes

Zooxanthellate soft corals are among the most ecologically important and dominant benthic organisms on tropical reefs of the Indo-Pacific. Previous taxonomic studies have described around 600 taxa of these sessile, photosymbiotic macro-organisms. However,

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identification of species based on morphology can often be unreliable and complicated by the group's phenotypic plasticity; this difficulty inhibits our understanding of the reef's ecology. Xeniidae and the Alcyoniidae are the two most diverse families of zooxanthellate soft corals. We used the molecular barcode mtMutS, a mitochondrial gene, to assign xeniids and alcyoniids to molecular operational taxonomic units (MOTUs) as proxies of species. With these assignments we surveyed the distribution of the two families throughout the Indo-Pacific. Cluster analysis suggested that there is little overlap in MOTU composition between the Indian Ocean and Pacific Ocean. Mantel regressions indicate a highly significant relationship between MOTU composition and the geographic distance between two collection sites, with closer sites sharing more species than distant sites. The strength of that relationship differed between the families, possibly due to their different reproductive strategies. Xeniids brood their larvae, leading to lower dispersal and more endemic species. Alcyoniids are broadcast spawners, which leads to higher dispersal and fewer endemic species. Regardless of reproductive strategy, the data suggest that the geographic ranges of species in both families are smaller than those commonly suggested by most taxonomic literature.

84-2 Lane, SJ*; Brewer, VB; VanDiest, IJ; Linkous, CR; Mabry, KE; Sewall, KB; Virginia Tech, Oregon State University, Kennesaw State University, New Mexico State University; *samjl89@vt.edu*

Maternal care increases with the presence of extra pair offspring in wild song sparrows

A number of biparental avian species once thought to be monogamous are now recognized to be socially monogamous and seek copulations with individuals outside of their social pair. Having a greater number of partners may benefit females by increasing the genetic diversity of their offspring. Females would be aware of the number of partners they had during the egg laying phase of a breeding attempt and we hypothesize that they would invest more in a clutch that had a higher probability of extra-pair young (EPY). We predict that maternal care, measured as nest visitation rates using radio frequency identification, would be higher in nests with the presence of EPY. We monitored maternal and paternal care, and extra-pair paternity rates of 27 song sparrow (*Melospiza melodia*)

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nests (37 individuals) in 2018 and 2019. Maternal visitation rates were higher in nests with EPY compared to clutches without EPY (p value = 0.0294). Additionally, maternal visitation rates increased with the number of extra pair offspring present in the nest (p value = 0.0273). Paternal visitation did not differ across EPY and non-EPY nests. This supports the idea that females invest more in nests with higher rates of extra-pair paternity. However, visitation rates are only a proxy of maternal investment. Despite higher maternal visitation, nests with EPY were less likely to fledge. Future studies should look at rates of extra-pair copulations and female investment to further examine female mate choice and maternal investment.

S4-12 Lanier, HC*; Connors, PK; Varner, J; Dizney, L; Duggan, JM; Erb, LP; Yahnke, CJ; Flaherty, EA; Hanson, JD; University of Oklahoma, Colorado Mesa University, University of Portland, California State University, Monterey Bay, Warren Wilson College, University of Wisconsin Stevens Point, Purdue University, Biodiversity Research and Education; *pconnors@coloradomesa.edu*

Connected while distant: Networking CUREs across classrooms to create community and inspire students

One hallmark of learning during COVID-19 is the feeling of isolation experienced by many undergraduate students. As classes pivoted online, many high-impact, high-touch teaching practices in STEM (e.g., Course-based Undergraduate Research Experiences, CUREs), have been lost. Over the last 5 years, CUREs have increased due to their potential to broaden opportunities for undergraduate students to gain research skills. However, many CUREs require specialized equipment or space, and are difficult to implement remotely. Here, we present an overview of Squirrel-Net, a network supporting ecology-focused CUREs that we have successfully transitioned to distance-based delivery. These CUREs engage undergraduates in authentic, course-based research focused on the ecology of squirrels. Because squirrels are easily seen and abundant in a range of habitats, they are an ideal system for students to develop their own scientific questions. Moreover, because our CUREs are performed outdoors, most without specialized equipment, they are easily transitioned online. Finally, the network connects classes and people; students contribute their data

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to national datasets to develop a shared resource, and courses from different institutions are connected through presentations and discussions. This project shows the positive student outcomes that arise from connecting classes and people, and from building a sense of scientific community around an integrated study system.

BSP-2-5 Lapsansky, AB*; Tobalske, BW; University of Montana; *anthony.lapsansky@umontana.edu*

Aquatic locomotion in non-aquatic birds and the secondary evolution of subsurface swimming

Subsurface, aquatic locomotion has evolved independently at least ten times across the avian phylogeny. Given the unique challenges associated with aquatic locomotion, it is uncertain how the re-invasion of the aquatic environment could occur. Water is 800 times denser and 60 times more viscous than air. Thus, secondary adaptation to water presumably requires significant morphological and physiology changes. One option is that lineages are 'pre-adapted' to subsurface aquatic locomotion through selection for efficient locomotion on the surface of the water. In our efforts to study the similarities between surface-based aquatic locomotion in non-aquatic birds and the subsurface swimming of semi-aquatic birds, we made a surprising discovery. European starlings (*Sturnus vulgaris*), a non-aquatic species, gracefully swim when placed underwater. Though this work is in its early stages, we can report a few observations relevant for understanding the evolution of subsurface swimming in birds. First, starlings use both their feet and wings for aquatic locomotion, but the feet appear to function primarily for directional control, as in true wing-propelled diving birds. Second, both the upstroke and downstroke of the wings are hydrodynamically active, with the upstroke producing negative heave and the downstroke producing both positive heave and thrust. And third, starlings adopt the flexed-wing posture exhibited by all volant, wing-propelled diving birds, suggesting that this posture is the result of biomechanical constraints rather than selection for efficient swimming. We plan to extend this work to more non-aquatic species, test whether individuals improve their swimming performance through learning, and rigorously compare the 3D kinematics of swimming in non-aquatic species to that of true semi-

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aquatic birds, including the European starling's close relative, the American dipper.

87-7 Larkin-Gero, ER*; Leroy, A; Hart, JA; Hart, TB; Brown, M; Detwiler, KM; Florida Atlantic University, Santa Ana College, Frankfurt Zoological Society, DRC , Frankfurt Zoological Society, DRC , UC Santa Barbara; *elarkingero2018@fau.edu*

Molecular systematics and phylogeography of the blue monkey, Cercopithecus mitis, in Central and East Africa

Cercopithecus mitis is a polytypic, pan-African guenon species with a complex evolutionary history and unresolved taxonomy. Many populations are found in remote locations leading to an incomplete survey of the species and lack of phylogenetic data. The current IUCN Red List recognizes *C. mitis* as one species with 16 subspecies. This study investigates the phylogenetics of two forms within the *C. mitis* radiation: *C. m. stuhlmanni* and *C. m. heymansi*. The *C. m. heymansi* population is localized and endemic to the Tshuapa-Lomami-Lualaba (TL2) Conservation Landscape in the central Congo Basin, whereas *C. m. stuhlmanni* has a wide distribution, from the eastern Congo Basin in DRC to western Kenya. We used a multi-locus, bi-parental approach to determine the phylogenetic relationships of these taxa. We sequenced the *cytb* locus of the mitochondrial genome and the TSPY gene of the Y-chromosome of samples imported from wild populations with known provenience (n=28). Incongruence was found between the gene trees for both subspecies. *C. m. heymansi* forms highly supported monophyletic clades in both trees, indicating that *C. m. heymansi* is a distinct lineage within the *C. mitis* radiation. *C. m. stuhlmanni* exhibits paraphyly in both trees, suggesting an evolutionary history shaped by historical climatic fluctuations which led to isolation followed by secondary contact. An increase in genetic data and a more complete sampling of the *C. mitis* radiation is needed to fully resolve the phylogenetic relationships within the species and implement taxonomic revisions to better reflect the level of diversity within the taxon.

92-13 Laroche, RAS*; Weinersmith, K; Angeloni, LM; Wiegmann, DD; Egan, SP; Rice University, Houston, Colorado State University, Fort

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Collins, Bowling Green State University, Bowling Green; *rall1@rice.edu*

Is energetics or competition a stronger driver of the seasonal timing of reproduction by male smallmouth bass?

Energy reserves are important in determining reproductive behavior in many species. In fishes, mature males vary greatly in size and larger individuals have lower metabolic rates and higher energy reserves. Male smallmouth bass, *Micropterus dolomieu*, invest significant energy into parental care. In northern populations, where adults do not forage over the winter and rely on pre-existing energy reserves, adult males must recoup winter energy losses before initiating reproduction. However, males also exhibit territorial behavior, defending their nesting site from other male competitors before reproduction. We used a 10-year dataset to test the hypothesis that energetic allometry, rather than competition, controls seasonal reproductive timing by male *M. dolomieu* of different sizes. We found that larger males required fewer degree days (a measure of thermal energy experienced) before reproducing each year, which is consistent with the energetics hypothesis. Also, timing of peak reproduction was negatively related to the number of degree days accumulated early in a breeding season. Lastly, we found that changes in measures of growth between seasons better predicted changes in timing of reproductive behavior by males that spawned in two consecutive seasons than changes in measures of competitive ability. Together, these results suggest that timing of reproduction in this population is more strongly influenced by energetic constraints than competition.

36-5 Larouche, O; Hodge, JR; Alencar, LRV; Camper, B; Adams, DS; Zapfe, K; Friedman, ST; Wainwright, PC; Price, SA*; Clemson University, Yale University, University of California, Davis; *sprice6@clemson.edu*

Does pharyngognathy unlock body shape diversification in acanthomorph fishes?

We use the repeated evolution of pharyngognathy within acanthomorph fishes, a commonly cited key innovation, as a case study to explore the predictions of key innovation theory. Specifically, we investigate whether transitions to pharyngognathy led to shifts in the rate of phenotypic evolution, as well as shifts and/or

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expansion in the occupation of morphological and dietary space, using a dataset of eight morphological traits measured across 3853 species of Acanthomorpha. Analysing the six evolutionarily independent pharyngognathous clades together we found no evidence to support pharpharyngognathy as a key innovation; however, comparisons between individual pharyngognathous clades and their sister did reveal some consistent patterns. In morphospace, most pharyngognathous clades cluster in areas that correspond to deeper-bodied morphologies relative to their sister clades, while occupying greater areas in dietary space that reflect a more diversified diet. Additionally, both Cichlidae and Labridae exhibited higher univariate rates of phenotypic evolution compared with their closest relatives. However, few of these results were exceptional relative to our null models. Our results suggest that transitions to pharyngognathy may only be advantageous when combined with additional ecological or intrinsic factors, illustrating the importance of accounting for lineage-specific effects when testing key innovation hypotheses. Moreover, given the challenges we experienced formulating informative comparisons, despite the ideal evolutionary scenario of multiple independent evolutionary origins of pharyngognathous clades, we suggest a reassessment of the expected impacts of key innovations may be warranted.

36-3 Larouche, O*; Gartner, SM; Westneat, MW; Evans, KM; Rice University, Houston, TX, University of Chicago, IL; *ol4@rice.edu*
The parrotfish beak leads to shifts in cranial integration patterns and increased morphological disparity
A pervasive property of biological systems that is thought to structure patterns of morphological diversification is a modular organization among anatomical components. Modularity may facilitate the emergence of evolutionary novelties by allowing some integrated subsets of traits to follow quasi-independent evolutionary trajectories. Among wrasses (Labridae), one highly consequential morphological innovation is the modification of the oral jaws into a beak-like structure in the parrotfishes, as it allowed these species to effectively expand their dietary niche to also include hard coral skeletons. Here, we explore some of the consequences associated with the appearance of the beak in parrotfishes on

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patterns of phenotypic evolution for various elements of the cranium. We compiled a three-dimensional morphological dataset of cranial osteological structures and used geometric morphometrics to quantify skull shape variation across 158 wrasse species. We then applied phylogenetic comparative methods to compare patterns of morphological integration and disparities between parrotfishes and other wrasses. We found that parrotfishes exhibit a number of changes in their integration patterns relative to other wrasses: integration is increased among the oral jaw bones (i.e. dentary, maxilla and premaxilla), whereas integration is reduced between the elements of the hyoid apparatus and most other cranial structures. Moreover, all osteological structures examined were more morphologically disparate in parrotfishes compared to other wrasses. These differences may reflect an increased modularity of the parrotfish cranium, possibly owing to functional considerations associated with a shift in prey capture method from suction feeding to primarily biting.

S11-2 Larson, G; University of Oxford; *greger.larson@arch.ox.ac.uk*
Dog domestication through an ancient evolutionary lens
Despite numerous investigations leveraging both genetic and archaeological evidence, the geographic origins of dogs remain unknown. On the basis of an ancient Irish dog genome and an assessment of the spatiotemporal appearance of dogs in the archaeological record, a recent paper suggested that dogs may have been domesticated independently in Eastern and Western Eurasia from distinct wolf populations. Following those independent origins, a mitochondrial assessment suggested that the Mesolithic dog population in Western Europe may have been replaced by a population from the East. To test these and other hypotheses, we are generating nuclear genomes from ancient dog remains from sites across the Northern Hemisphere, and mitochondrial genomes from ~1000 dogs spanning the last 15,000 years. The results of these analyses are revealing the ancestral affinities of dogs that were present across the Old World and we are beginning to understand the the timings and movements of dog populations through time and space. The combination of an archaeological time depth with the resolution of whole genomes is allowing us to reveal the history of our longest and fondest domestic partner.

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92-7 Lasala, JA*; Bernhard, MC; Mazzarella, KT; Mote Marine Laboratory, Sarasota, FL; *jlasala@mote.org*

Longitudinal study of sea turtle nesting behavior on a large Gulf of Mexico rookery

Longitudinal data sets are essential to the study of imperiled organisms. This is especially true for species that have long life history stages that are largely difficult to study due to their location, such as marine turtles. Examining trends over time can reveal changes that might not be evident from a standard census. These data are critical for conservation managers to properly assess recovery. For marine turtles, one of the best ways to estimate population size is to examine nesting numbers and extrapolate how many individuals are actively nesting within a community. Further productivity metrics examine nest success (successful nests / not-successful attempts), nest hatch success (number of eggs hatched) and emergence success (number of hatchlings leaving the nest). These values frequently fluctuate from year to year due to nest placement, predation, and storm activity. The Sea Turtle Conservation and Research Program of Mote Marine Laboratory has been monitoring nesting turtles on 35 miles of coastline on five islands off the Florida Gulf coast since 1982. They have documented close to 120,000 turtle crawls and almost three million hatchlings leaving the beach. In this talk, we will compare nesting success and nest productivity across the five islands over this thirty-nine-year dataset and discuss how nesting trends in this region are actively contributing to this imperiled population.

38-4 Lattanzio, MS*; McCann, M; Manion, M; Christopher Newport University, Newport News, VA; *matthew.lattanzio@cnu.edu*

Geographic variation in the ecomorphology and thermal ecology of a widespread lizard

Studies of ecomorphology reveal fascinating examples of how natural selection can mold intra- and interspecific variation in morphology-habitat associations. Despite a growing appreciation for the influence of other factors on these associations (e.g., sexual selection), our understanding of the consequences of spatial

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variation in their expression remains limited. Given the known ties between habitat selection and thermoregulation, one underappreciated outcome of such variation might be concomitant divergence in a species' thermal ecological traits. We capitalize on morphology, habitat use, and thermal data collected on adult sagebrush lizards (*Sceloporus graciosus*) from eight populations distributed throughout the species' geographic range to address this limitation. In terms of their morphology, we detected no overall sexual dimorphism in body size, but there was consistent male-biased dimorphism in limb lengths and head width. Although head width and jaw length variation were unrelated to habitat use, larger lizards and lizards with longer legs exploited more open habitats compared to smaller individuals. These ecomorphological patterns were associated with concomitant variation in thermal traits: specifically, substrate temperatures varied geographically, and jointly these temperatures and habitat configuration predicted parallel variation in lizard body temperature. In general, lizards exploiting warmer perches and more heterogeneous habitats attained higher body temperatures. Overall, these findings provide some evidence that lability in thermal traits might be an underappreciated outcome of geographic variation in ecomorphology, possibly providing an important buffer against variable environmental conditions throughout a species' range.

82-1 Lattin, CR*; Johnson, KM; Kelly, TR; Louisiana State University, California Polytechnic State University; *christinelattin@lsu.edu*

Constitutive gene expression differs in three brain regions important for cognition in neophobic and non-neophobic house sparrows (Passer domesticus)

Neophobia ("fear of novelty") is often repeatable within individuals and across contexts, suggesting it reflects an animal's underlying exploratory temperament, and neophobia can affect the ability of wildlife to adapt to new challenges and opportunities. Despite the ubiquity and importance of this personality trait, however, the molecular mechanisms underlying neophobia are poorly understood. We first screened a group of wild-caught house sparrows (*Passer domesticus*) for neophobia in the lab using novel object tests. We then selected a subset of the most and least neophobic

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individuals (n=3 of each) and used RNAseq to assess transcriptomes of four brain regions involved in learning, threat perception, and executive function in birds: striatum, hippocampus, nucleus taeniae of the amygdalae (TnA), and nidopallium caudolaterale (NCL). We found significant overall effects of brain region, phenotype (neophobic vs. non-neophobic), and a brain region by phenotype interaction. Comparing neophobic and non-neophobic birds revealed constitutive differentially expressed genes (DEGs) in three brain regions we examined: hippocampus (~12% of the transcriptome), striatum (4%) and NCL (3%). Two ontology-based analyses (Gene Ontology and Eukaryotic Orthologous Group annotations) revealed that the majority of enriched terms across all brain regions were in transcripts upregulated in neophobic birds, and were broadly distributed across structural, signaling, and metabolic processes. These results suggest that some behavioral differences in neophobic and non-neophobic birds may be due to underlying DEGs in the brain that create structural, signaling, and metabolic differences between the two phenotypes.

104-6 Laurence-Chasen, JD*; Arce-McShane, FI; Hatsopoulos, NG; Ross, CF; University of Chicago; *jdlc700@gmail.com*

The effect of oral anesthesia on jaw and tongue kinematics during feeding in Macaca mulatta

The oral cavity is richly innervated with mechanoreceptors that provide information about bolus characteristics. It is hypothesized that this information is important for modulating tongue and jaw movement to achieve coordinated, efficient chewing and swallowing. To test this hypothesis, we performed an intraoral lidocaine nerve block on multiple sensory branches of the trigeminal nerve to temporarily silence sensory signals from mucosal and periodontal mechanoreceptors while preserving motor and proprioceptive signals to and from the jaw and tongue muscles. We collected biplanar videoradiographic data before and immediately after the nerve block and quantified jaw and tongue kinematics using XROMM (n=2 *Macaca mulatta*, both male). We found that in the absence of tactile sensation average feeding sequence duration, in terms of number of cycles, increased. Chewing after the nerve block was more rhythmic (i.e., more consistent cycle durations) and the temporal relationship between gape and tongue tip anteroposterior reversal

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became more stereotyped. Furthermore, average gape magnitude remained consistent but within-sequence variation in gape magnitude decreased significantly after the block. On the whole, our results suggest that proprioceptive inputs from jaw and tongue muscle spindles are sufficient for successful feeding but that tactile and periodontal inputs play a key role in modulating kinematics for efficient food breakdown, as evidenced by longer feeding sequence durations as well as reduced variation in cycle duration and gape magnitude in the nerve block condition.

102-9 Laver, RJ*; Hunziker, J; Bauer, AM; Daza, JD; Australian National University, Canberra, ACT, Australia, Sam Houston State University, Huntsville, TX, USA, Villanova University, Villanova, PA, USA; *rebeccajlaver@gmail.com*

A bone of contention - The search for wormians in squamates

Wormian bones (WB) are additional ossifications that typically occur in cranial sutures, most common in mammals, particularly the akinetic skulls of humans. In contrast, WB are perceived as rare in reptiles; to date, only two studies record observations in squamates. We surveyed >1,200 skulls spanning 1,123 species from 71 families of lizards and snakes. We observed the roofing bones using predominantly microCT data, supplemented with detailed specimen sketches from skull descriptions, and photographs of cleared and stained specimens. We found WB in lizards from *Agamidae, Xantusiidae,* and a variety of gecko species from *Diplodactylidae, Gekkonidae, Pygopodidae* and *Sphaerodactylidae*, as well as in multiple snakes from *Colubridae, Elapidae, Typhlopidae* and *Xenotyphlopidae*. The majority of WB were found between the parietals and the supra- or ex-occipitals, the second most common position was the frontoparietal suture. Frequently the WB occurred as singular bones, and along the mid-sagittal plane; although in some instances the WB was asymmetrical (on only one side of the skull), or two asymmetric WB occurred. The WB themselves also varied in size and shape. This study indicates that, whilst these elements are still rare, they appear to have been overlooked in the past. However, increasing generation of microCT data may allow for more frequent detection, particularly when it is more common knowledge that they occur in squamates. Better quantification of these bones across reptiles may also give

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us greater power to elucidate reasons WB arise where they do, and to assess possible functions or even constraints of these accessory bones within the more kinetic skulls of squamates, and in particular, snakes.

52-6 Lawrence, AB*; Hammond, AS; Ward, CV; Department of Pathology and Anatomical Sciences, University of Missouri, Division of Anthropology, American Museum of Natural History & New York Consortium in Evolutionary Primatology; *austin.lawrence@mail.missouri.edu*

Acetabular orientation and pelvic shape in hominins

Hominin pelvic form differs dramatically from that of other primates by having more laterally facing iliac blades, a wider sacrum and a larger, transversely broad pelvic inlet. Acetabular orientation appears to differ as well, plausibly related to differences in load transmission during habitual bipedal posture and locomotion, which may, in turn, affect overall pelvic geometry. We compared acetabular orientation in humans, *Australopithecus* and extant anthropoids using two approaches. First, we measured the 3D orientation of the acetabulum on *in silico* models of individual hipbones aligned to the median plane by registering models to landmark coordinates that had been collected on articulated pelves. We fit a plane to the acetabular rim and measured its orientation relative to median, transverse and coronal planes. Second, we performed 3D geometric morphometric analyses of landmarks collected on whole pelves and on acetabula alone of 30 extant taxa, humans and *Australopithecus*. Results show the acetabulum is inclined further anteriorly and inferiorly in hominins compared to all other anthropoids. Acetabular orientation is generally equivalent among non-hominin anthropoids. Humans and *Australopithecus* have equivalent orientations despite differences in hip joint size, inlet breadth and iliac morphology. These data suggest that hip joint orientation is independent of these other aspects of pelvic form. Geometric morphometric analyses show that acetabular reorientation in hominins also influences the mediolateral breadth of the lower ilium. These results suggest that the orientation of the acetabulum is a key component in the suite of pelvic characteristics related to habitual bipedality in hominins.

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86-6 Lawson, AB*; Hedrick, BP; Echols, MS; Schachner, ER; Louisiana State University Health Sciences Center, School of Medicine, New Orleans, LA, Mobile Avian Surgical Services, The Medical Center for Birds, Oakley CA; *Adam.B.Lawson@gmail.com*

Anatomy, variation, and asymmetry of the bronchial tree in the African grey parrot (Psittacus erithacus)

The bronchial tree of the avian respiratory system is an elaborate, interconnected network of roughly parallel and unidirectionally ventilated air conduits. Descriptions of bronchial tree organization and the connected air sacs of the lung have traditionally relied on dissection and corrosion casts of their negative (air-filled) space. The bronchial trees of five deceased African grey parrots (*Psittacus erithacus*) were segmented from micro-computed tomography scans into three-dimensional (3D) surface models and assessed for structural variation. Additionally, select quantitative metrics from the primary bronchi and major secondary branches of 11 specimens were acquired and statistically analyzed for intraspecific variation and left-right asymmetry. Analysis of the 3D reconstructions revealed variation in the number and distribution of secondary bronchi with consistent direct connections to specific respiratory air sacs. A single reconstruction of the tertiary bronchi (parabronchi) network revealed indirect connections to all but two of the nine total air sacs. Statistical analysis revealed significant left-right asymmetries between the primary bronchi and the origins of the first four secondary bronchi (the ventrobronchi). This work advances our understanding of a widely studied avian taxon and represents an enhanced quantitative method for assessing avian gross pulmonary anatomy at an unprecedented level of detail.

58-7 Le Gall, M*; Cease, AJ; Arizona State University; *marionlegall314@gmail.com*

Generational variation in nutrient regulation for an outbreaking herbivore

Multivoltine insects are capable of producing multiple generations in one year. Favorable conditions support more generations, leading to serious outbreaks. For herbivorous insects, plant nutrient

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availability is a major environmental factor affecting fitness and it can shift substantially throughout seasons. Most organisms can adopt several strategies to regulate their nutrient intake and maximize performance in a variable environment. However, data regarding nutrient regulation of wild herbivores are scarce, and even more so regarding potential intergenerational plasticity. To bridge this gap, we measured nutritional regulation and performance of an outbreaking multivoltine herbivore, the Senegalese grasshopper (*Oedaleus senegalensis*). We surveyed a field population in Senegal and measured its nutritional preference and regulation across two generations (G1 and G3) using artificial diets and plant choice experiments. We found that not only G1 and G3 locusts selected different protein:carbohydrate ratios, but also that the strength of regulation was different. G1 locusts regulated their nutrient target more tightly than G3 locusts. In contrast, most studies with laboratory colonies have found that across generations, grasshoppers tend to have strong and consistent nutrient regulation. Both generations selected a carbohydrate-biased nutrient ratio, although it was more carbohydrate-biased for G3 locusts. However, plant nutrient contents in the field were more protein biased than their preferred diet. G1 females were heavier and laid more eggs than G3 females. However, G3 locusts survived longer during the experiment, suggesting a potential generational trade-off between reproduction and survival. Our results provide important insight on the interplay between nutrient availability in the field, nutrient regulation strategies, and performance in the context of outbreaks and persistence of populations.

109-3 Le Pogam, A*; Drolet, J; Young, K G; Régimbald, L; Roy, G; Robitaille, F; Laplante, M-P; Berteaux, D; Tam, A; McRae, C; Love, OP; Vézina, F; Université du Québec à Rimouski, Centre d'Études Nordiques, Centre de la Science de la Biodiversité du Québec, Rimouski, QC, Université du Québec à Rimouski, Rimouski, QC, University of Western Ontario, London, ON, Department of National Defence, Astra, ON, University of Windsor, Windsor, ON; *audrey.lepogam@uqar.ca*

Delayed spring conditions force Arctic snow buntings to maintain winter thermogenic capacity while breeding

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In most passerine birds, several body composition traits (e.g., body mass, fat reserves, muscles mass) decrease during breeding. However, a recent study on outdoor captive snow buntings (*Plectrophenax nivalis*) demonstrated a carry-over effect of winter cold acclimatization during the spring and part of summer, where most traits were maintained at winter level despite facing summer temperatures much warmer than on the breeding grounds. This suggest that snow bunting likely (1) maintain high cold endurance during migration and may (2) face a double physiological costs during breeding, having to support a winter phenotype while upregulating other traits for reproduction. This study aimed at testing these hypotheses. Between 2016 and 2019, we compared body composition (body mass, fat reserve and pectoral muscle thickness) and metabolic performance (thermogenic capacity and physiological maintenance costs) of birds captured on their wintering grounds (Rimouski, QC) and before breeding in the High Arctic (Alert, NU). We then studied how these traits changed from pre-breeding to chick provisioning in reproductive buntings at Alert. Our results confirm that buntings maintain a high thermogenic capacity and associated traits between winter and pre-breeding period, indicating that they likely maintain winter cold endurance during migration. While body mass, fat reserves and hematocrit decreased significantly through breeding stages, pectoral muscle thickness and thermogenic capacity seemed to decrease only from a certain temperature set point (~1.5° C) each year. These latter results suggest that buntings may be forced to maintain winter-level cold endurance late into the summer on colder years, independently of their breeding stages, which could imply additional physiological costs potentially affecting reproduction.

BSP-11-3 Leahy, AM*; Fish, FE; West Chester University; *AL916349@WCUPA.EDU*

Not to be flip: Anatomy and novel tendon morphology of the California sea lion hindflipper

The hindflippers of California sea lions (*Zalophus californianus*) have previously been overlooked as aquatic control surfaces. Although passively trailed and adducted in rectilinear swimming, the hindflippers are abducted during turning maneuvers. As the anatomy of sea lion hindflippers had not previously been described

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in detail, examination of the anatomy and morphology of the hindflippers were completed via scaled morphological measurements, CT scan, and dissections. Between the adducted and abducted postures of the hindflipper, there is a mean 22.6% increase in planar surface area. Flexible extensions of the digits beyond the distal phalanx gives the trailing edge of the flipper a crenellated appearance. Representing 17.2% of the total length of the hindflipper, the crenellations are composed of a collagenous matrix with no bony elements. The skeletal framework of the hindflipper is similar to that of human feet with modifications that create the characteristic delta shape. While most of the muscle origins and insertions of the hindflipper are similar to those in human feet, major differences exist. Abductor Hallucis and Flexor Digitorum Brevis have extrinsic origins in the hindflipper compared to intrinsic origins in humans. The tendons of Flexor Hallucis Longus and Flexor Digitorum Longus insert into the matrix of the crenellations as opposed to insertions onto the distal phalanges. The tendon morphology of Flexor Digitorum Brevis includes a foramen, through which the tendons of Flexor Digitorum Longus pass. These anatomical differences indicate an increased demand for the ability to abduct the hindflipper and the novel tendon morphologies suggest the possibility of active stiffness modulation of the digits and crenellations, which may assist in aquatic maneuvering performance.

S9-12 Leary, CJ; University of Mississippi; *cjleary@olemiss.edu*
Glucocorticoids, acoustic communication and sexual selection in treefrogs
Despite evidence that elevated glucocorticoids (GCs) can reduce investment in reproductive behaviors and growing interest in understanding how the stress response relates to fitness, there has been little emphasis on the role of GCs in sexual selection. I will discuss ongoing research in my lab examining the role of GCs in intra- and intersexual selection in the green treefrog, *Hyla cinerea*. In this species, males competing for mates engage in vocal contests using distinct amplitude-modulated aggressive signals. We have shown that hearing these calls can increase circulating levels of GCs in other males, especially small males that characteristically lose aggressive contests. Acoustic modulation of

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GC levels during male interactions, in turn, alters temporal aspects of male advertisement calls. For example, GC administration results in a rapid decrease in the duration of male advertisement calls and vocal effort. I show that these GC-mediated effects on vocal attributes are evident in natural populations i.e., circulating GC levels explain a significant proportion of the variation in the calls of chorusing males. I will present results from recent phonotaxis experiments showing that GC-mediated effects on the characteristics of male advertisement calls have a significant impact on mate choice by females, with females showing strong preferences for the calls of males with low GC levels. I will then present results showing that the strength of female preferences for male call characteristics may be contingent upon circulating GC levels, with weaker preferences exhibited by females with high GC levels. Together, these findings indicate that GCs can play a major role in both intra- and intersexual selection. I will discuss these findings in the context of selection on the stress response.

32-9 Lebeck, B; Kiefer, V; Winkler, M; Eareckson, C; Lippert, M; Hill, M*; University of Richmond, Richmond VA, Bates College, Lewiston ME; *mhill@bates.edu*

Size-selective mortality in the large bodied sponge Ircinia campana and changes in mesograzer crustacean populations and communities after Hurricane Irma in the Florida Keys

Hurricane Irma made landfall in Cudjoe Key, Florida at 13:00 UTC on the 10th of September 2017 at Category 4 intensity. In the years prior to the hurricane, we had been studying the sponge and mesograzer populations in the shallow flats to the south of the Mote Marine Laboratory's Elizabeth Moore International Center for Coral Reef Research & Restoration, which is approximately 5 km from Irma's landfall. These data allowed us the opportunity to compare pre- and post-hurricane features of sponge and mesograzer populations in this habitat. We conducted preliminary surveys in the flats 3 months after the hurricane, which revealed significant damage to the largest individuals of the vase-shaped sponge *Ircinia campana*. We followed the recovery of this sponge for the next two years, and examined hurricane-induced shifts in population structure. In addition to work with this sponge, we examined the

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responses of mesograzer populations to the hurricane the year after the hurricane. Several of the mesograzers that we examined showed significant shifts in body size. We discuss these patterns in the context of ecosystem resiliency in the face of major disturbances. We consider our findings in the context of the sponge loop hypothesis, which states that biodiversity in tropical habitats is supported by the detritus-producing capabilities of sponges. Our work highlights short-term and potential long-term impacts of hurricanes on these important tropical marine habitats.

45-7 Lebenzon, JE*; Sinclair, BJ; Western University, London, Ontario, Canada; *jlebenzo@uwo.ca*

Suppress to impress: Mechanisms underlying diapause and metabolic suppression in the Colorado potato beetle

Temperate insects spend over half their lives overwintering, weathering sub-zero temperatures, low resources, and hypoxia if they overwinter underground. To overcome these challenges in advance of winter, many insects enter diapause, a preprogrammed state of dormancy. Diapausing insects stop development, increase stress tolerance, and suppress metabolism. We only have a broad understanding of the physiological changes that occur during diapause in insects. Our aim was to elucidate the mechanisms driving diapause in the Colorado potato beetle. Beetles increase stress tolerance and suppress their metabolism by ~90% during diapause, however we do not know which specific molecules and biological processes drive these changes. Thus, our main objective was to investigate the molecular mechanisms underlying stress tolerance and metabolic suppression during diapause. We hypothesized that there would be tissue-specific shifts in the transcriptome of beetles during diapause that are consistent with stress tolerance and metabolic suppression. We used an -omics to generate specific hypotheses, some of which we then tested using physiological experiments and RNAi knockdown. Using RNA-seq, we identified expressed transcripts in tissues of diapausing beetles that encode chaperone proteins, and proteins involved in protection and repair from oxidative stress, suggesting that cytoprotection is integral for acquiring stress tolerance during diapause. We also identified expressed transcripts involved in mitophagy-driven metabolic suppression and showed that preventing mitophagy through

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RNA interference knockdown in diapausing beetles can reverse metabolic suppression. Our study is the first investigation of gene expression during diapause in the Colorado potato beetle using both an 'omics and functional hypothesis testing approach.

71-11 Lee, ECS*; Young, NM; Rainbow, MJ; Queen's University, Ontario, University of California, San Francisco; *erin.lee@queensu.ca*

3D glenohumeral range-of-motion in living and fossil primates, predicted in silico from skeletal morphology

Primate glenohumeral morphological features are frequently used to infer functional demands in living and extinct taxa. This mapping of form-to-function is confounded, however, when applied to fossils that display a mosaic of features with different functional associations. Here, we present a quantitative "six-degree-of-freedom" model and predict the glenohumeral range-of-motion (ROM) of nine living and fossil species from skeletal geometry, sampling hominoids and Old World monkeys. We simulated 82584 positions spanning all three rotational degrees of freedom and defined the ROM as positions where the humeral head and glenoid maintain congruence. We quantified *mobility* - a function of the size of the ROM - and a *functional region* - the abduction angle around which the joint has its most rotational freedom. Primates who engage in suspensory activity (ie. gibbon, orangutan, and chimpanzee) had greater mobility and higher functional regions compared to more terrestrial quadrupeds such as the gorilla and mandrill. The ROM of modern humans was intermediate. Interestingly, *Australopithecus sediba*, a fossil hominin suggested to have retained arboreal traits, exhibited ROM characteristics most similar to humans. Our model captures the complex interaction between features on articulating surfaces, allowing us to predict ROM that is not evident from comparisons of discrete morphological traits. For instance, the difference in ROM of the chimpanzee and gorilla is consistent with observed locomotor behavior, despite qualitative similarities in bone features. This framework enables a thorough functional interpretation of glenohumeral morphology and can be used to reconstruct the forelimb function of ancestral nodes in primate evolution.

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61-10 Lee, CE*; Stern, DB; Posavi, M; University of Wisconsin, Madison; *carollee@wisc.edu*

Selection on physiological plasticity and balanced polymorphisms during rapid invasions

The ability of populations to expand their geographic ranges, whether as invaders or climate migrants, presents among the most serious global problems today. However, fundamental mechanisms regarding factors that enable certain populations to rapidly transition to novel habitats remain poorly understood. In recent years, many species have invaded freshwater habitats from saline environments, such as the copepod Eurytemora affinis complex. We found evolutionary shifts in genome-wide in gene expression and parallel genomic signatures of selection across the saline to freshwater transition, both in wild populations and laboratory selection lines. Notably, these evolutionary changes often converged on the same ion transporters. Interestingly, we found significant correlations between acclimatory and adaptive responses in gene expression for these ion transporters. The significant plastic responses at critical loci might provide the substrate for selection during invasions. Moreover, we found significant reduction in plasticity in gene expression response at the same ion transporters in the freshwater invading populations, relative to their saline ancestors, consistent with the evolution of canalization over time. In a population genomic analysis, we found that a large portion of loci under parallel selection in the invasive populations arose from balanced polymorphisms in their native ranges (at the same SNPs within the same ion transporter paralogs!). Our findings have relevance for other invaders crossing this salinity boundary, as well as for understanding the nature of mechanisms that underlie rapid evolution during radical environmental change.

BSP-1-3 LeFauve, MK*; Kawano, SM; Hernandez, LP; George Washington University; *mlefauve@gwu.edu*

Can you hear me now? Shoaling in a sensory-limited environment

A shoal is a nonrandom group of fish swimming together in a loose cluster. Shoaling is an excellent proxy for organismal function in

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an ecosystem as it is a critical behavior that aids in food acquisition, reproduction, and predator avoidance. Shoaling behavior is complex, with individuals frequently changing position, and likely requires multiple sensory modalities. All cypriniform fishes possess a Weberian apparatus, a series of bones connecting the swim bladder to the inner ear, that amplify sounds. Cypriniform fishes are noteworthy in that while they are hearing specialists that often use their vision preferentially for hunting and social behaviors. This study aimed to test the limits upon which sensory modalities can change shoaling behavior in cypriniform fishes. Shoaling behavior was assessed using side preference, kinematics, and behavioral motifs in an open field with vision and hearing access or just hearing access to an artificial shoal of species conspecifics or heterospecifics. Preliminary results on side preference suggest that an obligate shoaling species, the giant danio, may be able to form conspecific-biased shoals when only given auditory access to the artificial shoal. Kinematic results suggest that visual access to conspecifics may be required to perform investigative behaviors, such as excursions, in both facilitative shoaling and obligate shoaling species. These results suggest that there may be stronger evolutionary pressure for multimodal sensory flexibility in obligate shoaling species.

96-9 Legg, A*; Lessios, N; Assumption University; *amelie.legg@assumption.edu*

Can branchiopod crustaceans detect predators and/or prey using multimodal sensory integration?

Branchiopods are a group of crustaceans that are often found in temporary pond habitats. These crustaceans have reduced central nervous systems in comparison to other Pancrustaceans, a group which includes insects and crustaceans. Branchiopods have sensory organs which can detect mechanosensory and light information; however, it is unknown how branchiopods use mechanosensory cues, or how they might integrate information from their sensory organs. A well-known example of aquatic Pancrustaceans which use pressure wave information to detect prey includes the backswimmer, which can detect prey in pond habitats. Additionally, arthropod multimodal prey detection has been identified in medicinal leeches. Some work suggests that medicinal leeches use a range of mechanical, visual

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and combined cues to detect prey in the water. If we compare multimodal cues presented to medicinal leeches to branchiopods, we can identify if branchiopod crustaceans use multimodal information to detect predators and prey. To explore this question, we use two groups of branchiopods that are often found to cohabitate the same temporary ponds: tadpole shrimp, and fairy shrimp. These branchiopods differ in their ecologies. Tadpole shrimp are benthic scavengers while fairy shrimp are freely swimming suspension-feeders. Studying how organisms that have reduced central nervous systems process multimodal cues from their environment is especially relevant to understand sensory processing and integration in arthropods.

86-1 Leiblich, A; Heyduk, K*; Edwards, E; University of Hawai'i, Honolulu, Yale University, New Haven; *heyduk@hawaii.edu*

Leaf anatomical evolution in three origins of CAM photosynthesis

Most plants are capable of photosynthesis, but not all plants photosynthesize in the same way. There are at least two alternative modes of photosynthesis in flowering plants, one of which - Crassulacean acid metabolism, or CAM - is found in about 8% of angiosperms and has evolved at least 80 times independently. CAM plants open their stomata for gas exchange at night, when transpiration is relatively lower than during the day, and store incoming CO2 as malic acid. In the daytime, the malic acid is decarboxylated and surrounds Rubisco behind closed stomata, essentially concentrating CO2 in the leaves. Moreover, there is great variation in the degree to which a plant uses CAM. Some species, called "strong" or constitutive CAM plants, obtain nearly all their CO2 via CAM, while other species use CAM only a fraction of the time. To assist with storage of malic acid, it is thought that strong CAM plants require large, densely packed cells in the leaves. However, our understanding of how anatomy evolves relative to the biochemical pathway of CAM remains unclear. Preliminary data in the Agavoideae (Asparagaceae), which includes iconic desert species like agaves and yucca, showed three independent origins of CAM in the subfamily. Furthermore, evidence suggested that large cells evolved before CAM, perhaps to aid with water storage in arid habitats. Here we broadened sampling and measured leaf anatomical traits in ~50 species in the Agavoideae to investigate leaf

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anatomical evolution across the subfamily and within the three CAM lineages. We further examined the association between historical climate, CAM, and anatomical trait evolution across the subfamily. In contrast to early data, we find that independent CAM lineages in the Agavoideae possess very different anatomical traits, suggesting they have each independently evolved or elaborated on CAM-like leaf anatomy.

53-7 Leibold, DC*; Valencia, V; Gangloff, EJ; Telemeco, RS; California State University - Fresno, Ohio Wesleyan University; *dleibold@mail.fresnostate.edu*

Metabolic recovery from exertion depends on the form of perturbation in lizards

Aerobic scope (AS), the difference between maximum (MMR) and resting metabolic rates (RMR) of oxygen consumption, is increasingly recognized as a valuable ecologically-relevant measure of organismal performance. However, measuring AS can be difficult because it requires eliciting MMR. In terrestrial vertebrates, MMR is typically measured via respirometry after either running animals to exhaustion or training them to walk on treadmills. The exhaustion and treadmill methods can be prohibitive in study scope, time, and money. We tested a novel method for eliciting MMR by perturbing lizards within flow respirometry chambers using a commercially-available, remote-controlled robot. We compared RMR, MMR, respiratory quotient (RQ), and recovery patterns for lizards treated with both the exhaustion and novel robot perturbation methods. RMR did not differ between methods, while MMR was greater when elicited via robot perturbation, which suggests robot perturbation is superior to the exhaustion method for measuring AS. Although recovery time did not differ between methods, post-recovery metabolic rate was greater than RMR when MMR was elicited via robot perturbation, and was less than RMR when MMR was elicited via exhaustion. The different post-recovery metabolic states we observed suggest that the stimulus used to elicit MMR has differing effects on long-term organismal energetics, possibly because of the physiological stress state elicited by both methods. This is in line with a growing body of literature proposing that physiological responses to stressors are context dependent rather than fixed, highly-repeatable responses.

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33-1 Leinbach, SE*; Speare, KE; Strader, ME; Auburn University, University of California, Santa Barbara; *sel0051@auburn.edu*
Coral host recovery and resistance strategies following a thermal bleaching event in French Polynesia
Coral bleaching events are predicted to become more frequent and severe in the future; however, there is substantial variation within populations in bleaching susceptibility and the ability to recover. In April and May 2019, the French Polynesian island of Moorea experienced a massive heat anomaly, resulting in the most severe mass bleaching event ever recorded for the island. At the most severely impacted sites, 80% of *Acropora* colonies bleached or died, although we observed differences in the prevalence and severity of bleaching across sites and reef zones. Further, within highly impacted sites, we observed *Acropora hyacinthus* showing signs of symbiont recovery by August 2019, with full recovery of most colonies by October 2019, suggesting that these corals harbor mechanisms to persist and recover following extreme thermal stress. Here, we aimed to understand if differences in energetic components and symbiont community composition explain the two observed survival strategies of resistance and recovery in *Acropora hyacinthus* colonies along the north shore of Moorea. We collected small coral fragments 0, 3, and 5 months post-bleaching from colonies located in three reef zones (forereef, crest, and backreef) for amplicon sequencing of the ITS2 region to characterize the Symbiodiniaceae community diversity, as well as samples to quantify changes in host protein reserves. Ultimately, this study will reveal spatial and temporal variation in resistance and recovery strategies of natural coral populations faced with climate change-induced heat stress.

52-9 Leite, JV*; Barrett, PM; Goswami, A; The Natural History Museum, London and University College London, UK, The Natural History Museum, London; *j.vasco-leite@nhm.ac.uk*
Metacarpus evolution in non-avian dinosaurs: a 2d morphometrics perspective
The manus of terrestrial tetrapods is involved in various environmental interactions, including locomotion, food acquisition

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and many more, meaning that complex selective pressures have acted upon its morphology. Non-avian dinosaurs are an excellent group to study manus shape evolution given their wide range of body sizes, stances, and ecological niches. Their ancestral bipedal bauplan allowed diverse morphologies to evolve, but multiple independent reversions to quadrupedality likely imposed convergent mechanical constraints on manus form. I present a study on metacarpus shape evolution in non-avian dinosaurs using 2D geometric morphometrics. Photographs and published images of the five metacarpals (pentadactyl ancestral state) in dorsal view were obtained for 87 taxa, representing all major clades. Shape variation of each element was quantified using four landmarks and four curves of 50 semilandmarks. Phylogenetically-informed Principal Component Analysis (PCA) and MANOVA, analyses of disparity and evolutionary rates were conducted using the R packages *geomorph*, *phytools* and *mvMORPH*. Morphological convergence was tested using *RRphylo*. Allometry had a significant effect (up to 17%), the first PCA axis explaining over 74% of shape variation, separating taxa with longer, slender metacarpals from those with proportionally shorter shafts and wider proximal/distal ends. Substantial differences between bipedal and quadrupedal taxa were not found, but results suggest two quadrupedal morphotypes: stout metacarpals in thyreophorans, ceratopsians, and some basal sauropodomorphs; longer, slender elements in sauropods and hadrosauroids. In sauropodomorph and ornithopod evolution there is a clear convergence toward a more ‘columnar’ manus structure.

51-5 Lenard, A*; Diamond, SE; Case Western Reserve University; *axl710@case.edu*

Changes in morphological traits along an urbanization gradient in the cabbage white butterfly

In contemporary history urban areas have expanded and created a suite of novel environmental conditions for organisms living within cities. With characteristics such as increased temperatures, urban environments have garnered interest from ecologists and evolutionary biologists aiming to understand the current effects of urban pressures and use urban populations to forecast how organisms might adapt to warmed conditions. Recently, many studies have documented urban-driven changes to morphological and physiological

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traits. Here, we explore the effects of urbanization on two morphological traits, body size and coloration, in butterfly populations. We used cabbage white butterflies (*Pieris rapae*), a cosmopolitan butterfly found in abundance in both urban and non-urban environments. The melanic wing pattern of *P. rapae* is plastic in regards to environmental temperature, with individuals reared at warmer temperatures exhibiting lighter coloration. While these patterns have been observed seasonally, there is no evidence to whether butterflies in urban areas have decreased coloration compared to their non-urban conspecifics. Using field-caught and lab-raised individuals we evaluate differences in coloration and body size and find sex-specific patterns in trait divergences.

S4-2 Lent, DD*; Hansen, AK; California State University, Fresno; *dlent@csufresno.edu*

Making interdisciplinary learning continuous across education

More and more, we see that advances in life sciences are made because of Interdisciplinary collaborations. These collaborations are the future - they are necessary to solve the world's most pressing problems and grand challenges. But are we preparing the next generation of scientists and the community for this future? At the K-12 level, progress is being made to make learning interdisciplinary through the implementation of the *Next Generation Science Standards* (NGSS). NGSS is inherently interdisciplinary, it identifies core ideas in life science, earth science, physical science, and engineering/technology. As NGSS is implemented, it will fundamentally change life sciences education at the K-12 level. At the University level, *Vision and Change* aims to reintegrate biology education and makes a strong argument that for students to build core competencies in biology, their education needs to be interdisciplinary. However, the biology courses offered to students for their undergraduate education are often siloed, with limited integration across disciplines. Interdisciplinary learning needs to be continuous across education, beginning in K-12 and lasting throughout university. We need to increase partnerships and collaborations throughout a student's life sciences education as this will enhance curricular continuity and reciprocally strengthen interdisciplinary life sciences education at all levels.

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100-5 Leonard, KM*; Williams, TD; Simon Fraser University; *kathryn_leonard@sfu.ca*
Do female social networks influence timing of egg-laying in European starlings?
Research on social factors as cues for timing of egg-laying have focused on the roles of male song and display. Although male and female song can have similar functions (e.g. competition mediation, intra-pair communication, predator defence, territoriality), female song is still poorly understood. Recent studies demonstrate benefits of female-female interactions and synchrony of egg-laying, including gaining information on environmental conditions, matching food availability with provisioning, group foraging to locate food, and stimulation of ovarian development and reproductive behavior. Positive social interactions between females might therefore fine-tune laying date, increase breeding synchrony, and enhance reproductive success, whereas negative female social interactions (stress, territorial aggression, nest box takeovers) will likely disrupt social networks and breeding synchrony. In European starlings (*Sturnus vulgaris*), highly social birds that exhibit semi-colonial living and synchronous breeding behaviors, spring temperatures predict timing of egg-laying, but in some years actual and predicted laying dates deviate significantly. I will use social network analysis including proximity to, and familiarity with, other females, to determine if female social interactions explain residual variation in laying date at both the individual and population level. Ultimately, I plan to experimentally investigate the relationship between female social interactions and timing of breeding. I will use a compilation of pre-breeding female vocalizations recorded at nest boxes to conduct a female-specific song-playback aiming to manipulate laying date by inducing positive social stimulation (advancing laying) or negative social stimulation (delaying laying date).

11-1 Leslie, CE; Rosencrans, RF; Walkowski, W; Gordon, WC; Bazan, NG; Ryan, MJ; Farris, HE*; University of Texas - Austin, University of Alabama - Birmingham, LSUHSC - New Orleans, LSUHSC - New Orleans; *hfarri@lsuhsc.edu*

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Reproductive state modulates retinal sensitivity to light in female tungara frogs

Although most studies of hormonal modulation of anuran behavior have focused on acoustic communication, recently more studies have addressed the modulation of vision, in general, and the retina, in particular. The predominance of auditory work stems from the fact that most anurans are nocturnal and consequently use elaborate acoustic signaling. Over the past decade, however, work has shown that visual cues are also used in mating decisions, even under nocturnal conditions. This study examined how experimentally induced reproductive state affects such low-light visual processing. To do this, we performed electroretinograms (ERGs) to determine the retinal sensitivity of túngara frogs (*Physalaemus pustulosus*), a neotropical species whose mating behavior includes visual cues. ERGs were recorded under scotopic and photopic conditions in frogs that were either non-reproductive or hormone-treated with human chorionic gonadotropin (hCG) prior to testing. We also took optical measurements to determine how túngara frog eye and retina morphology related to ERG sensitivity. As expected, we found that both sexes display higher visual sensitivity under scotopic compared to photopic conditions. However, hormone injections significantly lowered scotopic retinal thresholds of females. This change enabled full use of predicted optical sensitivity and suggested modulatory mechanisms specific to mate searching conditions and rod-based vision. These results support the hypothesis that hormonal modulation of neural mechanisms, such as those mediating visually guided reproductive behavior in this species, include sensory organs: the retina.

8-9 Lessig, EK*; Hofmann, HA; The University of Texas at Austin, The University of Texas at Austin ; *elessig@utexas.edu*

Towards the neural basis of social attention hierarchies

Social interactions require knowledge of the environment and status of others, which can be acquired indirectly by observing the behavior of others. When being observed, animals can also alter their signals based on who is watching. Attention structures of this kind are fundamental to competently navigating a dynamic social world and depend on advanced social cognition capabilities along with mechanisms for assessing, evaluating, and responding to

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a variety of social cues. Given the importance of attention structures in social groups it is surprising how little is known about the underlying neural mechanisms. Here, we use the highly social African cichlid fish, *Astatotilapia burtoni*, to assess how socially dominant males - after having experienced a simulated territorial intrusion - adjust both their attention and behavior when a neighbor is subjected to the same treatment. Following intrusions, we harvested blood and brains from males to assay circulating levels of steroid hormones and neural activity patterns throughout the social decision-making network, respectively. Our results show that males are keenly aware of their social environment and adjust their behavior strategically for reproductive and social advantage. This work increases our understanding of individual's social interactions by taking an integrative approach to examine behavior and the neuromolecular basis of such behavior.

97-10 Lessner, EJ*; Holliday, CM; University of Missouri; *ejlessner@mail.missouri.edu*

Ecomorphology and morphological diversity of trigeminal nerve-mediated somatosensation in sauropsids

Understanding the morphology of tissues mediating sensory perception is essential to understanding organismal behavior. Cranial somatosensation in living reptiles requires dense innervation of the mandibles by the trigeminal nerve to receive and discriminate between the range of stimuli experienced during sensory behaviors including prey acquisition, feeding, and navigation. Morphological diversity of both the soft tissue and osteological trigeminal system is unexplored across reptiles, and thus relationships between form and function are unknown. Additionally, inferences of facial sensation in extinct vertebrates are often loosely based on qualitative descriptions of bony features of the trigeminal system. Using CT and hand-measured data, we explore morphometric relationships between and among soft tissue (i.e., trigeminal ganglion, inferior alveolar nerve, terminal sensors) and osteological (i.e., trigeminal fossa, inferior alveolar canal, rostral foramina) trigeminal structures of extant representatives from each major clade of sauropsids with diverse sensory strategies. Exploring the trigeminal mandibular division,

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we find relatively larger trigeminal structures in crocodylians than most birds and lepidosaurs, implying differing levels of sensory ability among taxa. We show canal branching patterns reflect sensory ecologies as well, with only tactile-foraging taxa exhibiting dendritic canals. Finally, we identify phylogenetic and ecologic factors influencing osteological correlate utility and predict sensory ecologies of extinct reptiles, supporting a trend of increasing trigeminal sensation along the crocodylian line. Overall, these findings describe some of the diversity of the reptilian trigeminal system and establish evolutionary patterns of reptile trigeminal ecomorphology.

67-2 Leveque-Eichhorn, L*; Grunbaum, D; George, SB; University California Berkeley, Georgia Southern University; *georges@georgiasouthern.edu*

Larval stage, temperature, and phytoplankton patches affect sea star (Pisaster ochraceus) swimming behavior

Due to elevated late-Spring/early-Summer snow melt, the Salish Sea is experiencing more frequent freshwater intrusions from nearby watersheds. Not only does this fresh, warmer, and more nutrient-rich water cause an overall warming of the Salish Sea (18° C), but it also creates ideal conditions for thin phytoplankton layer formation. To investigate whether sea star larvae are able to successfully swim and feed in these increasingly common phytoplankton patches, the swimming behavior of younger (bipinnaria) and older (brachiolaria) *Pisaster ochraceus* larvae was examined in the presence and absence of food at 12° C and 18° C. Four treatments were run at each temperature: halocline without food, halocline with food patch, no halocline without food, and no halocline with food dispersed. For each treatment, 700-750 larvae were used and 2-2.5 minute videos were taken at the depth associated with the halocline. Videos were then analyzed using particle tracking software, Python, and Rstudio. Older larvae consistently swam faster and were typically more abundant at the halocline compared to younger larvae. When larvae were swimming in a halocline, they were faster when a food patch was present for both stages. Older larvae turned more frequently in a food patch compared to when food was dispersed. In thin phytoplankton layers, and especially at elevated temperatures, both larval stages are

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likely to swim faster, potentially conferring advantage to feeding, and older larvae are likely to increase turning frequency. Importantly, both larval stages were able to swim and feed within a food patch at 12° C and 18° C, implying that these larvae are able to take advantage of these resource patches. However, the extent to which these larvae cope with changing food distribution in the Salish Sea may be largely dependent on life stage, with older larvae benefitting more from these thin phytoplankton layers.

109-4 Levesque, DL; University of Maine; *danielle.l.levesque@maine.edu*

Thermoregulatory phenotypes in mammals: the missing link between basal metabolism and life history?

Basal metabolic, equivalent to the idling speed of mammals (measured during rest in non-reproductive, mature, fasted animals) is highly variable in mammals. Based on the hypotheses put forward by the Metabolic Theory of Ecology higher basal metabolic rates are expected to correlate with higher reproductive outputs. Yet in mammals this has consistently been shown to false. I argue that the level and degree of body temperature regulation (which also varies considerably among mammal species) as well as environmental temperatures, and the difference between the two, are key to understanding the lack of relationship between metabolic rates and reproductive outputs. Tropical and subtropical small mammals, for example, routinely experience temperatures above the lower critical limit of the thermoneutral zone and often have highly variable body temperatures. Therefore, unlike temperate species that must consistently generate heat to maintain an elevated body temperature, low latitude species spend more time at thermoneutrality and therefore can spend the energy elsewhere. I present an analyses of basal metabolic rates, body temperatures, thermolability, and life history traits in mammals and propose key areas in need of future research.

100-6 Levy, EJ*; Gesquiere, LR; McLean, E; Franz, M; Warutere, JK; Sayialel, SN; Mututua, RS; Wango, TL; Oudu, VK; Altmann, J; Archie, EA; Alberts, SC; Duke University, Oxford College of Emory University, Freie Universitaet Berlin, Amboseli Baboon Research

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Project, University of Nairobi, Princeton University, University of Notre Dame; *ejl37@duke.edu*

Alpha female baboons have the lowest glucocorticoid levels: What we can learn from comparing rank metrics

In group-living animals, dominance hierarchies are a common cause of unequal access to fitness-related resources. There are many different methods to measure dominance rank, including ordinal rank, proportional rank (i.e., standardized or relative rank), high-middle-low categories, alpha versus non-alpha status, and cardinal rank measures (e.g., Elo rating). We hypothesize that each rank metric makes a different assumption about resource availability and within-group competition. Using a large dataset of fecal samples from wild adult female baboons, we test the ability of five common rank metrics to predict fecal glucocorticoid concentrations as a proxy for psychosocial and energetic stressors. Surprisingly, alpha status was the best predictor of fecal glucocorticoids, with lower levels in alpha females relative to non-alphas, indicating fewer stressors experienced by alpha females relative to other adult females. We also observed a weak effect of proportional rank, with lower fecal glucocorticoids in high-ranking females than low-ranking females. Our work introduces a new and easy approach to gain insight into the competitive landscapes occurring in animal societies.

5-6 Levy, MG; University of California Berkeley; *mglevy@berkeley.edu*

Behavioral control of morphology in Cypraidae

The Cowrie is an aquatic snail whose shell is prized among shell collectors but whose biology is mostly not understood. Here we present a novel explication of both body and shell ontogeny emergent from mechanical constraints and a behavioral change. When sexually mature the snail extrudes its mantle through the shell aperture effectively turning its exoskeleton into an endoskeleton. This behavioral shift, in turn, changes the form of both the body and the shell. We describe quantitatively three novel features of the cowrie shell: deviation of its central spiral, labial thickening around the aperture, and ridges forming along said aperture (teeth). We couple elasticity, growth, and shell deposition in biophysical models to predict regimes of mantle

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mechanical properties consistent with the reported geometrical data. These models integrate and replicate the aforementioned shell features while enabling the charting of a morphospace suggesting why some evolutionarily related species, like the Ovulidae, have similar shell features while lacking apertural teeth. Our recurrent morphological models can be tied into the known evolutionary divergence of the family to select locations of probable discontinuities of mantle biophysical properties. Beyond this reduced modeling we also solve and show three dimensional renderings of cowrie shells based on our novel mechanical framework. Our work suggests a closed mechanical and behavioral feedback loop steering the development of a juvenile cowrie to its adult form.

52-5 Li, P*; Ross, CF; Luo, Z-X; University of Chicago; *peishu@uchicago.edu*

Morphological evolution of the primate hyoid apparatus

The mammalian hyoid plays an integral role in swallowing, respiration and vocalization. Anthropoid primates have broad, cup-shaped basihyals suspended from the basicranium by soft tissues only. This configuration differs from most placental mammals, which have a rod-shaped basihyal connected to the basicranium via both soft tissues and a mobile bony chain called the anterior cornu. To better understand how the unique anthropoid hyoid morphology evolved, we use linear morphometrics to quantify hyoid morphology in 35 primates and outgroup species. We show that dermopterans have variable loss of cornu elements. *Tupaia* and all lemuroids except *Daubentonia* have a fully ossified anterior cornu connecting a rod-shaped basihyal to the basicranium, an ancestral pattern of mammals. Haplorhines collectively have reduced anterior cornu, and further changes in basihyal aspect ratio and volume occur within anthropoids. Lorisoid strepsirrhines independently evolved reduced anterior cornu and broader basihyals similar to tarsiers. Primate hyoids follow a different allometric scaling pattern from other mammals, consistent with the scaling of larynx from previous studies. Among primates, anthropoids tend to have larger hyoids than allometry predicts, but strepsirrhines have smaller hyoids than expected. We hypothesize that anthropoids' enlarged ventral hyoids can support larynxes with hypertrophied air sacs. Their

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reduced anterior cornu may facilitate vocal tract lengthening to lower formant frequency spacing and exaggerate body size cues in vocalization. Anterior cornu reduction in anthropoids is also a prerequisite for the descent of larynx among modern humans. Our results highlight several novel evolutionary patterns of hyoids in primates.

BSP-7-4 Li, R*; Zarate, D; Avila-Magaña, V; Li, J; Ecology and Evolutionary Biology, University of Colorado Boulder, Boulder, CO; *ruiqi.li@colorado.edu*

Identification of Photosymbiosis-related genes in marine cockles (Subfamily Fraginae)

Photosymbioses between animals and photosynthetic algae have independently evolved in diverse marine lineages from single-celled foraminiferans to complex organisms such as corals and bivalves. This amazing relationship lays foundation of coral reefs - one of the most diverse and productive ecosystem in the ocean. However, molecular mechanisms behind such symbioses remain less understood, especially for non-cnidarian organisms, such as mollusks. In order to fill this gap, we use the marine bivalve subfamily Fraginae (heart cockles), which establishes photosymbioses with algal lineages from the family Symbiodiniaceae, as a model system to identify photosymbioses-related genes. In this study, we assessed differential gene expression patterns in three photosymbiotic species (*Fragum fragum, F. scruposum* and *F. sueziense*), each kept under three different light intensities (normal, reduced, and dark). We obtained a total of 176 transcriptomes from both mantle (symbiont containing) and foot (no symbionts) tissues of the three bivalves through RNAseq. The genes whose expression patterns were highly regulated by light intensities, and are uniquely expressed in symbiont-containing tissues were identified as candidate photosymbiosis-related genes. Their functions in the photosymbiosis process were explored.

71-9 Li, EY*; Lee, ECS; Young, NM; Rainbow, MJ; Brown University, Providence, Queen's University, Ontario, University of California, San Francisco; *ellen_li@brown.edu*

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The impact of cranial-lateral scapular shape variations on glenohumeral ligaments

The hominin fossil record is consistent with the evolution of the more laterally oriented joint of the modern human shoulder from that of a cranially positioned suspensory ancestor. Across humans, scapular shape does vary with cranial-lateral orientation correlated with changes in rotator cuff mechanical advantage. This study examined how cranial-lateral shape changes in the human scapula alters glenohumeral ligament function. This is important because the highly mobile shoulder is constrained partly by ligaments, thus changes in scapular morphology may lead to changes in ligament function. We created a novel approach by using PCA to generate shape models from n = 51 scapulae to capture the range of lateral and cranial orientation across humans and applied glenohumeral abduction kinematics to each shape model while optimizing for congruence. Ligaments were then modeled as fiber-reinforced finite element shells in Artisynth and ligament length was compared across shapes for inferior and superior ligaments at their extreme ranges of elongation. Compared to a laterally oriented glenoid, a cranially oriented glenoid had a 12.7% longer superior glenohumeral ligament at low abduction and an 8.3% shorter inferior axillary ligament at high abduction. However, the coracohumeral ligament displayed minimal variations across scapulae (2.5%) at low abduction. These results suggest that a cranially oriented scapula enables higher levels of abduction, which is consistent with arboreal primates possessing cranial scapulae that function at high ranges of abduction. However, changes in ligament length may occur with a cost to stability.

91-10 Li, N*; Flanagan, BA; Edmands, S; University of Southern California, Los Angeles; *ningli@usc.edu*

The effects of mitochondria on sex-specific transcriptomic responses to aging in the copepod Tigriopus californicus

Mitochondria enable cellular respiration and their functions have been known to influence normal senescence as well as a range of aging-related diseases. Mitochondrial replacement therapy has been suggested to cure mitochondrial diseases by replacing pathogenic mitochondrial DNA. However, mitochondrial function relies on over 1,000 nuclear-encoded genes whose products function in the

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mitochondria. The interactions between mitochondrial and nuclear genomes (mito-nuclear interactions) are essential to mitochondrial performance, and thereby promote intergenomic coevolution. *Tigriopus californicus* is an emerging model for understanding mito-nuclear interactions because viable hybrids are easily generated in crosses between geographical populations with divergent mitochondrial sequences. It has also been proposed as an alternative model system for sex-specific studies due to the absence of sex chromosomes. Here we developed *T. californicus* as a new invertebrate model system to investigate sex-specific gene expression, the role of mitochondria in aging, and the effects of mito-nuclear interactions on sex-specific aging. In this study, two populations with 20.6% mitochondrial sequence divergence were crossed to produce two parental lines and two reciprocal F1 hybrids. For each cross, survivorship was measured over the full lifespan, and single-individual transcriptome sequencing was performed at 28 and 56 days post hatching. The findings will contribute to a better understanding of the mitochondrial basis of aging and the potential effects of mitochondrial replacement therapy on human health and aging in both sexes.

24-3 Li, L; Wang, S; Chen, B; Song, S; Zhao, W; Wen, L*; Beihang University; *liwen@buaa.edu.cn*

The biomimetic remora disc with independent compartment enables an aerial-aquatic quadrotor robot perching to diverse complex surfaces

Remora suckerfish can attach to various marine hosts with diverse, complex surfaces using its adhesion disc pad. The remora disc can form independent compartments between adjacent lamellae when attaching to a substrate. The lamellae's spinules can engage with the surfaces while maintaining compartments' separate attachment. Meanwhile, the remora disc is flexible and can bend to adapt curved surfaces. The rigid skeleton structure and movement of lamellae are challenges for implementing a bio-inspired robot with independent compartments' adhesive ability. We designed a biomimetic, multi-material flexible remora disc (87 mm long, 40mm wide) with multiple rows of lamellae that can achieve independent compartments during attachment. Then we investigated its adhesion performance on rough, curved, damaged, and protruding artificial surfaces in a lab

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aquarium. We found that the biomimetic suction disc can attach to rough surfaces (grain size: 50 μm) for 49.1 ± 2.1 h underwater and 4.8 ± 0.3 h in air. The disc can also attach to the curved surface (radius of curvature: 50 mm), a surface with a hole (hole diameter: 25 mm), and a bumped surface (protuberance height: 1cm) in water and air. We further developed an untethered aerial-aquatic quadrotor robot equipped with the disc prototype. The quadrotor robot can reversibly transit between air and water to rapidly adhere to complex surfaces through various highly maneuvering modes. This robot is also capable of hitchhiking on moving objects. Our results may shed light on the future aerial-aquatic robots with the adhesive ability for dry and underwater environments.

105-8 Liao, JC*; Rajeev, E; Canestrelli, A; Ray, B; University of Florida, Gainesville and The Whitney Laboratory for Marine Bioscience, St. Augustine, University of Florida, Gainesville ; *jliao@whitney.ufl.edu*

Flooded forests in flow; trout exploit wakes behind multi-cylinder arrays

Fishes that exploit current-swept habitats commonly encounter the wakes behind multiple bluff bodies. To better understand how these wakes can repel or attract fishes, we studied the flow across multiple cylinders with both CFD and live fish experiments at Re=10,000. Our first set of experiments consists of 7 cylinders arranged in a single row in the streamwise direction. We analyze configurations in the co-shedding regime, i.e. for spacing larger than 1.9D, where D = cylinder diameter. We determined the optimal cylinder configurations that generates the most peaked velocity spectrum, for which the flow field consists of a coherent Kármán vortex street with a dominant vortex shedding frequency. These configurations consist of equally spaced cylinders, with spacing close to the wavelength of a vortex street shed from one single cylinder (2D). In a second set of experiments, cylinders are arranged in multiple rows. We determined the optimal cylinder configurations by varying both Lx (streamwise) and Ly (spanwise). We found a distinct range ($1.9 < Lx/D < 2.2$ and $3.3 < Ly/D < 3.5$, where D = cylinder diameter) of cylinder spacings that generate coherent vortices. If $Ly/D > 3.5$, there is no interaction between vortices and each cylinder row behaves as an individual row. If

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Ly/D <2.2, increased mixing will disturb the flow field. Trout (n=15, 5-9 cm total length) swimming at Re=10,000 avoid wakes where upstream cylinders (1.9 cm diameter) interact destructively with downstream cylinders (velocity = 52 cm s^{-1}). These arrangements produce weaker, more widely spaced and less-organized vortices that discourage Kármán gaiting. Rainbow trout hold station behind cylinder arrangements that promote the strongest vortex coherence across a range of flow speeds (50-90 cm s^{-1}). These findings suggest that certain arrangements of bluff bodies are more conducive to optimizing energy expenditure and migration than others.

BSP-9-3 Lichter Marck, IH*; Freyman, WA; Siniscalchi, CM; Mandel, JR; Castro-Castro, A; Johnson, G; Baldwin, BG; UC Berkeley and Smithsonian Institution; *ilichtermarck@berkeley.edu*

Phylogenomics of the rock daisies (Perityleae; Compositae) provides new perspectives on the evolution of fruit and flower traits

Rock daisies (Perityleae; Compositae) are a diverse clade of seven genera and ca. 84 minimum-rank taxa that mostly occur as narrow endemics on sheer rock-cliffs throughout the southwest U.S. and northern Mexico. Taxonomy of Perityleae has traditionally been based on morphology and cytogenetics. To test taxonomic hypotheses and provide new perspective on the evolution of characters emphasized in past treatments, we present the first densely sampled molecular phylogenies of Perityleae and reconstruct trait and chromosome evolution. We inferred phylogenetic trees from whole chloroplast genomes, nuclear ribosomal cistrons, and hundreds of low-copy nuclear genes using genome skimming and target-capture. Discordance between sources of molecular data suggests an underappreciated history of hybridization in Perityleae. Phylogenies support the monophyly of subtribe Peritylinae, a distinctive group possessing a four-lobed disc corolla; however, all of the phylogenetic trees generated in this study reject the monophyly of the most species-rich genus, Perityle. Using reversible jump MCMC, our results suggest that morphological characters traditionally used to classify members of Perityleae have evolved multiple times within the group. A base chromosome number of x=9 gave rise to higher base numbers in subtribe

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Peritylinae (x=12, 13, 16, 17, 18 and 19) through polyploidization followed by ascending or descending dysploidy. Most taxa constitute a monophyletic lineage with a base chromosome number of x=17, with multiple neo-polyploidization events. These results demonstrate the advantages and obstacles to next-generation sequencing approaches in synantherology while laying the foundation for taxonomic revision and comparative study of the evolutionary ecology of Perityleae.

S12-11 Lim, HC*; Bennett, KFP; Justyn, NM; Kingston, SE; Long, KM; Powers, MJ; Brawn, JD; Hill, GE; Braun, MJ; George Mason University and Smithsonian Institution, University of Maryland and Smithsonian Institution, Auburn University, University of Maine, University of Illinois Urbana-Champaign, Auburn University, University of Illinois Urbana-Champaign and Smithsonian Tropical Research Institute, Smithsonian Institution and University of Maryland; *hlim22@gmu.edu*

Genomics of sexually selected traits in an avian hybrid zone

Sexual selection produces some of the most extraordinary traits and behaviors found in nature and is believed to play a key role in speciation, yet the underlying genomics are not well understood. We analyzed the genomic consequences of sexual selection underlying asymmetric introgression in male secondary sexual traits across an avian hybrid zone. Where *Manacus candei* (white-collared manakin) and *M. vitellinus* (golden-collared manakin) come into contact in northwestern Panama, plumage color and behavioral traits of male *M. vitellinus* have introgressed under sexual selection into *Manacus candei* , producing populations that look and act like *vitellinus* but are genetically like *candei* . We show that the introgressing plumage traits are due to deposition of lutein and melanin pigments in collar and belly feathers, respectively. To determine the genetic basis of these traits, we resequenced genomes from two *Manacus candei*-like populations, one with golden collars and one with white, and from one *M. vitellinus* population. Comparison of these populations identified divergent genomic regions containing genes involved in carotenoid metabolism and melanization, and implicates additional signaling pathways that may be involved in feather development and gonadotropin expression.

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These findings provide a novel example of genomic targets and mechanisms regulating expression of secondary sexual traits.

7-1 Lin, YH; Siddall, R; Banerjee, H; Schwab, F*; Jusufi, A; Max Planck Institute for Intelligent Systems; *ardian@is.mpg.de*

Body and tail undulation measured and emulated by soft sensors provides insight on stiffness control through co-contraction

The primary approach to measure hyper-redundant animal body structures is the use of high speed cameras in a laboratory environment, which can deprive locomotion of its proper context. Challenging conditions and complex three dimensional (e.g. rainforest or aquatic) environments make the collection of field data difficult, and prevents a complete analysis of an animal's motion. We have developed liquid metal (eGaIn) based, hyper-elastic silicone strain sensors to measure local tail curvature with minimal impact on environment, mobility and body stiffness and therefore hope to enhance in situ biomechanics data collection without requiring manipulation of conditions. By not relying on imaging systems, long-duration data can be collected at very low latencies with minimal power and processing, and intricate movements can be measured in field experiments. This includes rapid tail surface righting, one of the first movement patterns observed in neonatal development. We propose utilizing soft sensors to measure subtle movements in aquatic animals as well as patterns of autotomized gecko tails. Ultimately, new insights into behavior, neuromuscular control and mechano-sensory receptivity can be gained. When connected to a soft undulating robotic fish with a tail beat frequency of 0.8-1.2 Hz, our sensor response is linear (R^{2}(/sup) = 0.952) with a relative error that is well modeled by Gaussian noise (st. dev. of 0.4%). We additionally produce a data-driven model of the soft fish biorobot, which tracks experimental data to 1% mean error in displacement. We use this model to offer broader insight into the efficacy of eGaIn strain sensing to record biological movement of body caudal appendages in animals.

94-3 Lingenfelter, B; van Breugel, F*; University of Nevada, Reno, NV; *fvanbreugel@unr.edu*

Tradeoffs in spatial integration of optic flow for visual velocity estimation in flying insects

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For a flying insect, estimating absolute ground speed is essential during behaviors such as tracking an odor plume, or keeping tracking of total distance travelled. Behavioral experiments indicate that insects are indeed capable of estimating absolute ground speed, however, the underlying mechanism remains unknown. The fundamental challenge is that insects only have access to measurements that provide relative information: vision provides a measure of optic flow which corresponds to the ratio of velocity and distance to nearby objects, whereas airspeed measurements provide a vector sum of ground velocity and wind velocity. To explore how an insect might decouple these relative measurements, we take a robotics-inspired-biology approach focused on the task of extracting absolute ground speed from noisy optic flow measurements. Mathematically, extracting absolute ground speed from optic flow requires non-zero accelerations, as well as estimating the time-derivative of optic flow. Through simulations and robotics experiments we find that there is a clear tradeoff in overcoming the challenge of differentiating noisy optic flow data. First, we show that errors in velocity estimates due to noise in the optic flow measurements can be reduced by spatially integrating optic flow across large receptive fields. Second, we find that in cluttered environments with multiple distinct objects at different distances, smaller receptive fields result in lower errors. Thus, for a given level of noise and environmental clutter, there exists an optimal size for receptive fields that balances this tradeoff. This observation may explain why flies have visual neurons with intermediate sized receptive fields, however, additional experiments are necessary to determine what the distribution of these neurons is.

20-4 Linkous, CR*; Guindre-Parker, S; Kennesaw State University; *clinkou1@students.kennesaw.edu*

Anthropogenic effects on European starling nestlings growth and cholesterol

Urbanization is a leading threat to wildlife, and anthropogenic habitat modifications may alter the resources that wildlife have access to. For example, urban centers may provide animals with abundant anthropogenic food sources, though these foods may be lower in quality than natural food sources. The impact of living in

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urban centers on the growth, physiology and behavior of birds remains equivocal and can vary across species. We studied two free-living populations of European Starlings (Sturnus vulgaris); one at an urban farm (high human density) and one at a rural farm (low human density) in Kennesaw, GA. We monitored 100 nestlings across both sites and collected weight measurements to generate growth curves and collected blood samples to measure nestling cholesterol (index of dietary fats) and triglycerides (index of fattening rate). We hypothesized that urban nestlings will have slower growth rates, lower triglycerides, and higher cholesterol than rural nestlings. We also hypothesized that chick growth rates will be correlated to their behavioral coping style, where slower growing nestlings will have slower breathing rates and reduced struggling rates when handled. Future research will increase sampling at additional sites along an urban to rural gradient, examine parental behavior in selecting food sources for their nestlings, and assess additional indices of health and fitness.

20-2 Lipshutz, SE*; Howell, CR; Buechlein, AM; Rusch, DB; Derryberry, EP; Rosvall, KA; Indiana University, Bloomington, University of Tennessee, Knoxville; *slipshut@iu.edu*

Behavioral and transcriptomic responses to sublethal thermal stress in zebra finches

In a changing climate, thermal challenges may have severe impacts on fitness as animals shift their investment between self-preservation and mating effort. Understanding thermal tolerance is essential for predicting species persistence in a changing climate, but molecular responses to sublethal thermal challenges are not well understood. Our experiment used zebra finches *Taeniopygia guttata*, a model songbird species that regularly experiences extreme temperature fluctuations in its native Australia. We exposed captive males to temperatures above (43° C, ‘hot), within (35° C), and below (27° C, ‘cold’) their thermoneutral zone for 4 hours. We characterized thermoregulatory behavior and gene expression in tissues important for reproduction - the posterior telencephalon, which contains song control nuclei, and the testis. We found significantly more panting in heat and piloerection in cold, indicating that thermal treatments affected behavioral responses. Both hot and cold treatments affected expression of

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hundreds of genes in the testis, but far fewer genes in the posterior telencephalon, suggesting the brain may be more buffered from extreme temperatures than gonadal tissues. In the testis, we identified thermally sensitive gene networks related to immune responses and spermatogenesis, which are consistent with temperature-related tradeoffs between self-maintenance and mating effort. Coupled with previous findings that thermal challenges reduce singing behavior and sperm quality, the sublethal effects of extreme temperatures may represent a threat to reproductive success, even in heat-adapted species.

S5-9 Liu, Y; Ben-Tzvi, P*; Virginia Tech; *bentzvi@vt.edu*
Towards dynamic locomotion of legged robots using biomimetic articulated robotic tails
The traditional locomotion paradigm of quadrupedal robots is to use dexterous (multi-degree-of-freedom) legs and dynamically optimized footholds to balance the body and achieve stable locomotion. However, by looking to nature, tails are widely used as appendages by animals to assist in maneuvering, balancing, manipulating, and propelling. The core advantage of using tails to assist locomotion is that tails can provide a means of influencing the body dynamics independent of the legs' ground contact. Therefore, using robotic tails to help legged robots to achieve agile locomotion becomes a natural direction of robotics research. With the introduction of a robotic tail, a new quadrupedal locomotion paradigm might be feasible whereby the leg complexity is reduced on the account of incorporating an on-board robotic tail system, especially multi-link tails since they can provide more control inputs. This paper explores this new paradigm by tackling the dynamic locomotion control problem of a reduced complexity quadruped with a robotic tail. For this specific control task, a new control strategy is proposed in a manner that the legs are planned to execute the open loop gait motion in advance, while the tail is controlled in closed loop to affect the quadruped body in the desired orientation. With these two parts working cooperatively, the quadruped can achieve dynamic locomotion. Partial feedback linearization controller is used for the closed loop tail control. Pronking, bounding, and maneuvering are tested to evaluate the controller's performance.

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The results validate the proposed controller and demonstrate the feasibility and potential of the new locomotion paradigm.

81-4 Liu, YL*; Bradley, S; Patel, AV; Bailey, CDC; Vickaryous, MK; University of Guelph; *yliu37@uoguelph.ca*

Comparative neuromorphology and function of Purkinje cells in geckos, mice, and chickens

The neuromorphology of cells in the brain varies both within and across species, the differences of which reflect their similar yet distinct functions. Purkinje cells (PCs) are one of the largest cell types in mammals and play a key role in regulating motor control and movement in the cerebellar cortex. While PCs are widely recognized as having elaborate dendrite branching patterns, with few exceptions, details of their neuromorphology have rarely been quantified. Here, we investigate the neuromorphology of PCs in three taxonomically distinct species: the leopard gecko (reptile), laboratory mouse (mammal), and domestic chicken (bird). Using a modified Golgi-Cox protocol, PC neuromorphology was quantified both between and within species. Using Sholl and branched structure analyses, neuromorphological differences were quantified within each species that indicate regional differences of dendrite complexity between cells. Across species, PCs in geckos and mice were comparable in terms of average dendrite length but differed significantly in complexity, with mice having a greater number of Sholl intersections closer to the soma. PCs in chickens were almost twice as long as those of geckos and mice, and had a greater average dendrite volume, diameter, and length. Our findings demonstrate that significant neuromorphological differences are present for PCs both within and across species, and may be related to aspects of phylogeny, and possibly ecology and functional morphology. To assess differences in PC function, ongoing experiments aim to determine whether differences in the electrophysiological properties of PCs correlate with the morphological differences observed.

S7-12 Llorente, B; ARC Center of Excellence in Synthetic Biology, Macquarie University and CSIRO Synthetic Biology Future Science Platform, Sydney, Australia; *briardo.llorente@mq.edu.au*

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Synthetic biogenesis of carotenoid-rich plastids for crop biofortification

Synthetic biology has opened a new dimension for the future of agriculture, where crops can be engineered with new and improved traits. The nutritional value of crops is one such trait that is of primary importance to be improved. Carotenoids are natural antioxidant pigments essential to human health and the main source of Vitamin A. However, humans cannot produce carotenoids and need to obtain them primarily through the consumption of plant-based foods. We have developed a novel and generalizable approach that enables the synthetic conversion of chloroplasts into carotenoid-rich plastids named chromoplasts. Besides serving to study a long-standing question in plant biology (i.e., plastid differentiation), this approach lays the foundation for developing more nutritious crops.

90-4 Lo, HKA; Chua, VA*; Chan, KYK; Hong Kong University of Science and Technology, Swarthmore College, PA; *vchua1@swarthmore.edu*

Fluoxetine impacts behaviors of non-target organisms in acidified ocean

Alterations in ocean carbonate chemistry caused by anthropogenic carbon dioxide are widely documented to adversely impact a wide range of marine taxa. Emergent pollutants, such as pharmaceuticals, are of pressing concern as they may act on non-target organisms. Nevertheless, the bioavailability and bioaccumulation of these pollutants are pH-dependent; however, the interactive effects of reduced pH and environmentally relevant concentrations of pharmaceuticals are rarely studied. Here, we exposed larvae of urchin (*Heliocidaris crassispina*) and ascidian (*Styela plicata*) to the antidepressant fluoxetine at environmentally relevant concentrations under future ocean conditions. Acidified urchin larvae swam with reduced horizontal speed and in straighter trajectories. Arm orientation was also affected by both pH and fluoxetine concentration, indicating a stronger prevalence of downward swimming in control pH and 100 ng/L fluoxetine compared to 0 and 10 ng/L. In contrast, ascidian larval behavior was only mildly affected by acidification and fluoxetine exposure, indicated by a change in relative proportion of actively swimming individuals. These observed behavioral changes take place at

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concentrations much lower than published lethal concentrations of fluoxetine, which have non-additive interactions with end-of-century acidification levels. Such sub-lethal impacts on behaviors can have population-level implications and highlight the need for improved pharmaceutical monitoring and control in coastal waters.

BSP-7-7 Lobert, GT*; Toh, MWA; Moran, AL; University of Hawai'i at Manoa; *gtlobert@hawaii.edu*

Large effect of small temperature changes on embryonic development of Antarctic invertebrates

The Southern Ocean surrounding Antarctica is the coldest ocean on Earth and many of the ectotherms that live there are highly stenothermal. For Antarctic fauna, few studies have investigated the effect of increasing temperature on early developmental stages; these are often more vulnerable to environmental stressors than later stages. We measured the thermal sensitivity of early cleavage of two Antarctic invertebrates, a pycnogonid (*Ammothea glacialis*), and a nudibranch (*Tritoniella belli*). Uncleaved zygotes were placed in a thermal gradient block and maintained at a range of 10 temperatures from -1.8° C (ambient) to 3.5° C until reaching at least the 16-cell stage. For both species, embryos reached the 16-cell stage in approximately half the time at the highest temperature compared to ambient (*A. glacialis* 16 vs. 35 d, *T. belli* 7 vs. 16 d). Q_{10} values across the whole temperature range were 6.4 for *A. glacialis* (n = 1 clutch) and 6.12±0.4 for *T. belli*, (n = 3 clutches), indicating high thermal sensitivity of early cleavage. Arrhenius plots showed no change in the thermodynamics of cleavage over the temperature range for 3 of the 4 trials. For one set of *T. belli*, development failed completely at and above 2.9° C; in all trials, abnormalities and mortality were more frequent at the higher temperatures. These data indicate that early cleavage rates of two Antarctic species are highly sensitive to increases in temperature, but also that there is considerable variation in embryos' ability to develop normally at temperatures > 4° C degrees above ambient. Funded by NSF-OPP-1745130 to ALM

89-9 Logan, ML*; Cox, CL; University of Nevada, Reno, Florida International University; *mike.logan1983@gmail.com*

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Genetic constraints, gene expression plasticity, and the importance of extreme weather events in the evolutionary response to climate change

Evolutionary adaptation may be vital for the persistence of ectothermic species under climate change. Increases in both the mean and variability of environmental temperature are occurring, and each of these variables may act as agents of selection on different traits that may not be heritable or have the capacity to evolve independently from one another. If the 'baseline' values of thermal performance traits cannot evolve, phenotypic plasticity driven by gene expression might become critical. We review the literature for evidence that thermal performance traits in ectotherms are heritable and have genetic architectures that permit their unconstrained evolution. Next, we examine the relationship between gene expression and both the magnitude and duration of thermal stress. We find that evolution in many species appears to be constrained by genetic correlations such that populations can adapt to either increases in mean temperature or temperature variability, but not both. Nevertheless, there is rampant capacity for plastic expression of the transcriptome in response to temperature shifts, with the number of differentially expressed genes increasing with the magnitude, but not the duration, of thermal stress. We use these observations to develop a conceptual model that describes how evolution is likely to progress as the climate continues to change. We argue that extreme weather events, rather than gradual increases in mean temperature, are more likely to drive genetic and phenotypic change in wild ectotherms.

S6-9 Logsdon, RM; Krakauer, AH; Hylback, A; Mitchell, K; Dryer, B; Forbey, JS; Patricelli, GL*; University of California Davis, Boise State University; *gpatricelli@ucdavis.edu*

Social information use in greater sage-grouse in response to habitat structure and social network

Courtship signals often vary over space and time; one cause of this variability is plastic adjustment of effort in response to the social environment. To make such adjustments, displaying animals need information about the social environment; but we know little about how the physical environment (e.g. open vs closed habitat structure) affects the accessibility and flow of this information.

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In greater sage-grouse, we have shown that lekking males adjust their courtship effort in response to presence, proximity, and behaviors of females, as well as the effort of competing males. Habitat structure is highly variable among leks, from low grass to dense sagebrush, which may affect the flow of information and thus display plasticity. We hypothesized that on leks with high sagebrush cover, direct visual information about female presence will be limited, favoring reliance on social information from competing males. To test this, we manipulated habitat structure on leks with temporary barriers that limited visibility; we presented acoustic cues of female presence using playback of female calls or visual cues through presentation of a robotic female. We used network-based diffusion analysis to examine whether males initiate strutting behaviors using social information from other males or by direct observation of females, and how transmission of information differs among treatments. Our results highlight the important role of interacting social and physical environments in favoring complex and variable signals.

19-4 Lohr, B*; Brown, M; Moyer, MJ; Hill, R; University of Maryland Baltimore County; *blohr@umbc.edu*

Age-related stereotypy in song of grasshopper sparrows

Females may exert selective pressure on temperate, territorial male songbirds by responding differentially to several categories of song features, including: song output, local song structure, song complexity, and vocal performance. Numerous studies have now shown female preferences for high performance song, including for songs that exhibit increased stereotypy. For species that produce songs with repeated notes having similar structure, older individuals may produce songs with a higher level of stereotypy when compared with younger individuals. In most such cases, singing involves extensive movements of the upper vocal tract, especially the bill. We investigated whether older male grasshopper sparrows (*Ammodramus savannarum*) produce more stereotyped songs. Territorial song in this species consists of a series of introductory notes followed by a rapidly produced trill, during which the bill is held open and does not track individual notes. We took two approaches to determine whether songs of a cohort of birds were more stereotyped at older ages: an evaluation of variation in several acoustic

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measurements of the song, and a cross-correlation metric that provided an index of similarity within and across songs. We found that as males aged, they sang more consistent (less variable) songs, despite a lack of associated bill movements during singing. We also found that song similarity was enhanced during comparisons that adjusted for absolute differences in frequency structure. This result suggests that absolute frequencies may remain somewhat more variable as birds age than relative frequency relationships within song.

55-5 Lomax, JJ*; Brainerd, EL; Brown University, Brown University ; *jeremy_lomax@brown.edu*

Double-jointed biting of the serrasalmid sp. Piaractus brachypomus

Pacu fish (Family: Characiformes) possess a deceptively simple lower jaw joint that does little to reflect the complexity of the full feeding apparatus. Within red-bellied pacu, *Piaractus brachypomus*, the quadrato-mandibular joint (QMJ) restricts the lower jaw to a single open-close hinge motion. However, these fish consume a wide breadth of foods, posing differing mechanical challenges, which the jaws and teeth must overcome and process. Through the use of X-ray Reconstruction of Moving Morphology (XROMM), we found that *P. brachypomus* can recruit an additional degree of freedom for jaw motion that permits modulation of feeding behavior on the basis of food type. We have observed that the neurocranial hyomandibular joint (NCHY) is capable of permitting up to 1.8 degrees of suspensorial protraction through rotation of the hyomandibula about a medio-lateral axis at the NCHY joint. Additionally, we observed that while the magnitude of rotations at the QMJ showed no significant differences food to food, the rotations of the hyomandibula varied on the basis of food type with brittle foods requiring 0.5 ± 0.025 degrees hyomandibular rotation on average, and tough foods requiring 0.9 ± 0.05 degrees of rotation (mean ± s.e.; n=19 *brittle*, n=21 *tough* chewing cycles from 2 individuals). These rotations are small, but they are large enough to protract the lower jaw by 1-2 mm and we confirmed that they exceed our precision threshold (± 0.2 deg) for measurement of this rotation. We suggest that in protracting the suspensorium, and by extension the connected lower jaw, the pacu is capable of changing the occlusal positioning of the upper and lower tooth

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rows. In doing so the pacu would have the ability to change whether teeth were best positioned to slice through those tougher foods such as grasses while shearing apart more brittle foods like seeds; both of which have been repeatedly found in stomach contents.

S12-13 Long, KM; Tobiansky, DJ*; Goller, F; Braun, MJ; Brawn, JD; Fuxjager, MJ; University of Illinois Urbana-Champaign, Brown University, University of Münster and University of Utah, Smithsonian National Museum of Natural History and University of Maryland; *daniel_tobiansky@brown.edu*

Sexual selection on the behavioral, physiological, and genetic dynamics of an avian hybrid zone

Hybrid zones are dynamic systems where natural and sexual selection act upon admixtures of species' genomes and behaviors. We leveraged a hybrid zone between the golden- and white-collared manakins (*Manacus vitellinus* and *M. candei*, respectively). Females of both species prefer yellow-throated and fast-performing males, suggesting these traits should spread into the *M. candei* range. We reassess the hybrid zone 25 years after the initial transect to determine hybrid zone movement. We identify the genetic and phenotypic transitions and find that these remain unchanged, indicating this hybrid zone remains stable despite putative female preference. Given this stability, we investigate how sexually selected behavioral traits may explain the constancy of the hybrid zone. We examine a socio-sexual display, the roll-snap, which males produce by rapidly hitting their wings together. Hybrids roll-snap at similar speeds to *M. vitellinus* (≈60 snaps/sec), and both groups display faster than *M. candei*. Paradoxically, hybrids show suppressed muscle performance (slower muscle twitch speeds). Further analyses suggest that hybrids bypass this constraint by using intrinsic speed/endurance trade-offs, amplifying display speed by sacrificing other elements such as display length (# of snaps). Thus, hybrids produce shorter displays than *M. vitellinus*. Our study suggests that performance trade-offs provide a route for sexual selection to shape a behavioral phenotype despite genomic incompatibilities, thereby allowing preferred display behaviors to persist, while potentially limiting phenotypic spread due to muscle suppression.

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102-2 Long, JH*; Eiltersen, M; Fjelldal, PG; Helvik, JV; Karlsen, T; Nordvik, K; Rusten, I; Støren, E; Totland, GK; Wiig, H; Kryvi, H; Vassar College, University of Bergen, Institute of Marine Research, Norway; *jolong@vassar.edu*

From head to tail, embryo to adult: the life cycle of the notochord of Atlantic salmon, Salmo salar

In vertebrate morphology, the notochord is seen as changing from a dominant axial system in embryos to a remnant in most adults. That view underplays the functional role of the notochord throughout development and in different body regions. Its dynamic functional morphology is highlighted by the complex life cycle of the Atlantic salmon, *Salmo salar*. Embryos hatch as alevins that burrow into gravel of the riverbed. Alevins emerge as fry to explore the bottom. Parr patrol the water column as active predators, and smolt migrate from river to sea, returning as adults to spawn. Does the life cycle of the whole animal match that of the notochord? To address this question we used a variety of techniques to track structural changes over time and across body regions. The notochord in the middle of the body is dominated by chordocytes that form vacuoles in fry, exchange vacuoles for extracellular lacunae in parr, regain them as smolts, and retain them as adults. The vacuoles and lacunae are correlated with changes in the hydrostatic pressure of the notochord that underscore how stiffness enhances locomotion. The situation is different for the notochord in the cranium and the caudal fin. The cranial portion forms an unsegmented bony cap that is then degraded by osteoclasts. The notochord in the caudal fin never forms bone in its sheath; instead, partial and robust transverse septae form from the sheath and are retained in adults. That the notochord changes continually and varies dramatically in different body regions highlights the dynamism of this fundamental vertebrate organ.

63-9 Lopez-Perez, JE*; Goessling, JM; Meylan , PA; Southeastern Louisiana University , Eckerd College ; *jorge.lopez-perez@selu.edu*

Sex-based trade-offs in the innate and acquired immune systems of Sternotherus minor

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Longevity patterns in most vertebrates suggest that females benefit most from maintenance investment. A reversed longevity pattern in loggerhead musk turtles (*Sternotherus minor*) allowed us to test theory of trade-offs between maintenance and survivorship. We tested the hypothesis that the sex with greater longevity has greater maintenance than the sex with shorter longevity. We also compared the following parameters between sexes: bactericidal ability (BA) and heterophil: lymphocyte ratios (HLR). Baseline blood samples were collected from turtles in the field; a subset of turtles was returned to a laboratory for experiments of acquired immune responses to sheep red blood cells (SRBC). We found no support for the original hypothesis of reversal in sex-dependent immune trade-offs (difference between sex SRBC titers:$p=0.102$; interaction between treatment and sex: $p=0.177$; difference between treatments: $P<0.001$; effect of sex on BA: $p = 0.830$; effect of sex on HLR: $p = 0.717$). However, we did find support for sex-dependent differences in immunity in the relationship between HLR and body condition (BCI) (effect of BCI on HLR: $p= 0.015$). In field conditions, we found that males with higher body condition indices express stressed phenotypes more than males with lower body condition indices ($p= 0.002$). However, females expressed similar stress loads across all body conditions ($p= 0.900$). Testosterone concentrations were assayed in free-living turtles and were not related to any of the immune parameters. Our results suggest that the immune systems play an important role in balancing sex-specific responses to different selective pressures in *S. minor*.

15-8 Lord, KA*; Li, X; Karlsson, EK; University of Massachusetts Medical School, Worcester MA and The Broad Institute of MIT and Harvard, Cambridge MA, UMASS Medical School, Worcester MA and The Broad Institute, Cambridge MA, UMASS Medical School, Worcester MA and The Broad Institute, Cambridge MA; *kathryn.lord@umassmed.edu*

A molecular perspective on the evolution of behavior in dogs

Dogs and wolves are genetically similar enough to reproduce, yet dog behavior has evolved, adapting to an anthropogenic niche. Major changes in dog behavior include ease in forming interspecies social bonds; as well as a reduction of hazard-avoidance behaviors. Both changes are largely shaped by experiences during the primary critical period of socialization, when the developing brain is

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highly susceptible to environmental influence. In wolves, this interval starts and ends two weeks earlier than in dogs. As a result, wolves experience a narrower set of sensory information than do dogs, even in identical environments. We hypothesize this shift in development may arise through a small number of genomic regulatory or coding changes, with major effects on adult behavior. To find these changes, we are conducting a pilot genome-wide study of 71 wolf-dog hybrids with a wide range of ancestry, allowing us to study the association of behavior and genetics in a single population with varying behavioral phenotypes. We collected DNA and assessed each subject's response to novelty. Using whole genome association and admixture mapping, we have identified regions associated with differences in reaction to novelty, and enriched for genes implicated in autism, a syndrome thought to result from disregulation during the primary critical period of socialization. By combining ethological and genomic techniques with the unique ancestry of the hybrid population, we gain new insight into the evolution of dogs.

44-2 Lough-Stevens, M*; Ghione, C; Urness, M; Hobbs, A; Sweeney, C; Dean, MD; University of Southern California; *loughste@usc.edu*
Male-derived copulatory plugs enhance implantation success in Mus musculus
Among a wide diversity of sexually reproducing species, male ejaculates coagulate to form what has been termed a copulatory plug. Copulatory plugs promote ejaculate movement and retention and inhibit female remating. Female mice mated to males that cannot form a copulatory plug, because the males lack the protein transglutaminase 4 (TGM4), also have fewer successful pregnancies, a phenomenon that is not simply related to reduced fertilization rates. Here we present evidence for a new function of the copulatory plug: the induction of implantation success in females. Using a modified embryo transfer method to control for sperm count and embryonic development, we found that females are less likely to implant when they copulate with males that cannot form plugs. Surprisingly, this result does not correlate with progesterone levels, an important hormone in implantation. We discuss three models to explain the connection between copulatory plugs and implantation, including the hypothesis that plugs contribute to a

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threshold amount of stimulation required for females to become favorable to implantation.

64-6 Love, AC*; Kodali, J; Grisham, K; DuRant, SE; University of Arkansas, Oklahoma State University, University of Arkansas, Oklahoma State University; *acl017@uark.edu*

Maternal disease history shapes how offspring respond to infection

Infectious diseases can have both short- and long-term behavioral and physiological effects on hosts, even after the infection has cleared. Thus, diseases experienced before breeding could have lasting impacts on parental reproductive behavior and physiology that ultimately shape the developmental environment of offspring. We previously documented that female canaries with more severe pathology during a recently cleared infection with the bacterial pathogen *Mycoplasma gallisepticum* (MG) lay heavier eggs and increase investment in parental care behaviors, suggesting that the severity of disease pathology experienced during a recent infection could drive investment in the subsequent breeding attempt. In the present study, we examined how maternal disease history influences offspring responses to infection by infecting juvenile offspring from control and MG-exposed mothers and characterizing their cellular and serological responses to MG infection. When exposed to MG, offspring from mothers that experienced a recent infection tended to have greater disease pathology than offspring from control mothers. While we observed post-infection shifts in antibody levels and white blood cell differentials in offspring from both control and infected mothers, offspring from MG-infected females had immune responses that resolved more quickly than offspring from control females. Additionally, offspring from mothers that experienced more severe disease pathology during a recent infection had stronger antibody responses to MG. This suggests that the severity of disease pathology experienced by mothers during recent infections could shape how future offspring respond to infection. This work will increase our understanding of how maternal infection shapes offspring traits relevant to disease susceptibility and disease transmission.

89-2 Love, A C; Wagner, G P*; University of Minnesota, Yale

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The creative role(s) of stress in evolution: from co-option to novelty

A growing literature has documented that stressful conditions can facilitate evolutionary change in populations. However, this facilitation of evolution in situations of stress concentrates on how rates of adaptive change track increasing rates of environmental alteration. A neglected aspect of stress in evolution is its creative role related to the origin of new organismal features (i.e., origin of novel cell types and characters). These novelties exhibit a key distinguishing feature: they have a systematic relationship with the stressors experienced in the ancestral population. The new trait is a specific and permanent compensator that has been co-opted for particular conditions of stress. Standard models focus on how populations "fight" stress generally through adaptive modifications of existing characters (stress-induced evolutionary adaptation), rather than how populations "fix" particular stressors through the origin of altogether new characters (stress-induced evolutionary innovation). Using multiple examples from different developmental processes, such as soma-germline differentiation in Volvocine algae, cAMP signaling for spore formation in slime molds, decidual cell type origination in placental mammals, and dorsal closure morphogenesis in fruit flies, we build a cumulative case for stress-induced evolutionary innovation via co-option of stress regulatory networks across eukaryotic taxa. We argue that this distinctive mode of evolution has been more influential in the evolutionary process than biologists have previously appreciated and points to new explanatory principles and a research program of comparative and experimental work to further study the creative role of stress in evolution.

98-3 Lowie, A*; Herrel, A; De Kegel, B; Wilkinson, M; Measey, GJ; O'Reilly, JC; Kley, N; Gaucher, P; Brecko, J; Kleinteich, T; Adriaens, D; Ghent University, Belgium, Ghent University, Belgium; M.N.H.N., France, N.H.M., UK, Stellenbosch University, South Africa, Ohio University, USA, Stony Brook University, USA, C.N.R.S., French Guyana, R.B.I.N.S., Belgium, Kiel University, Germany; *aurelien.lowie@UGent.be*

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Under pressure: the relationship between cranial shape and in vivo maximal burrowing force in caecilians (Gymnophiona)

Caecilians are elongate and limbless amphibians. Except one aquatic family, they all have an at least partially fossorial lifestyle. It has been suggested that they evolved sturdy compact skulls with fusion of ancestrally separate bones and tight sutures as an adaptation for head-first burrowing. Although their cranial osteology is well described, relationships between form and function remain poorly understood. In this study, we report data on *in vivo* burrowing forces for more than 120 specimens belonging to 13 different species. Over 80 caecilians were μCT-scanned and their skulls segmented. Using fixed and semi-sliding anatomical landmarks, we performed 3D geometric morphometrics to quantify skull variability across species. Finally, using correlation tests, linear models and two-blocks partial least squares, we investigated the relationships between the overall cranial shape and *in vivo* burrowing force in caecilians. Surprisingly, results show that despite differences in the head morphology across species, there is no relation between overall skull shape and this particular measure of burrowing performance. Although a phylogenetic signal may partly obscure the results, our conclusions join previous studies using biomechanical models and suggest that any differences in their degree of fossoriality are not driving the correlated adaptive evolution of head shape and maximal burrowing force. As the cranium has multiple functions such as feeding, and houses major sensory organs, or respiratory systems, further studies are needed to fully understand the selective pressures shaping the evolution of skull form.

33-9 Lucey, NM*; Haskett, E; Collin, R; Smithsonian Tropical Research Institute; *noelle.lucey@gmail.com*

Shallow hypoxia on diverse tropical reef systems is an underestimated threat for marine ectotherms

Shallow coastal deoxygenation is poorly documented in the tropics. Despite concurrent warming, little is known about how hypoxia and warming impact reef associated taxa. On the three different reef habitats in the Caribbean (CAR) and Equatorial Pacific (TEP) we measured oxygen and temperature, and used these measurements to calculate the amount of oxygen available for biological use over

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the last three years. The first site is a protected reef within a large bay, while the second site is nearby on a well-exposed reef facing the open ocean in the CAR. The third site is also well-exposed ocean facing, but is in the TEP and experiences upwelling. Seasonal hypoxia is prevalent each of these reef habitats, with cold-correlated hypoxia in the TEP and warm-correlated hypoxia in the CAR. Using *Echinometra* sea urchin sister species from both oceans, we relate the most severe conditions measured at these sites to their modern-day physiological capacity to both perform under and survive the conditions on the reefs they inhabit. The TEP *Echinometra* performs poorly after only two hours in hypoxia, and is unable to survive hypoxia when temperatures increase despite O_2 availability increasing with temperature. Conversely, the two CAR *Echinometra* species are better equipped to survive short bouts of hypoxia, even when coupled with high temperatures. However, performance trials suggest only one of Caribbean species is able to cope reasonably well with the most extreme conditions documented on the reefs. Results suggest that tropical marine biodiversity is at greater risk than previously thought due to shallow tropical hypoxia.

S5-3 Luger, AM*; Watson, PJ; Dutel, H; Fagan, MJ; Herrel, A; Adriaens, D; Evolutionary Morphology of Vertebrates, Ghent University, Belgium, Medical and Biological Engineering Research Group, University of Hull, UK, School of Earth Sciences, University of Bristol, UK, C.N.R.S./M.N.H.N., France; *allison.luger@ugent.be*

Testing the relationship of prehensile function and the musculo-skeletal morphology of chameleons using multi-body dynamics

A prehensile tail represents an adaptation that has evolved in numerous vertebrate and invertebrate lineages. Prehensility is the ability to hold and grasp firmly an object, combining flexibility and strength. Yet, what it takes to make a tail prehensile remains poorly understood. In taking prehensile-tailed chameleons as a model organism, we aim to decipher the links between the variation in the musculo-skeletal anatomy of the tail and prehensile function. A previous study focused on the morphological variation in tail vertebrae of prehensile and non-prehensile chameleon species using µCT data. Following the detailed description of the tail musculature, we aimed at investigating how shape variation in

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the caudal vertebrae and muscle arrangement relates to grasping function. A prehensile tail is capable of withstanding high mechanical loadings and torsion, which we expected to be reflected in the musculo-skeletal morphology. Based on a 3D reconstruction of the tail vertebrae and musculature, we used Multibody Dynamics Analysis to investigate the effect of variation in vertebral shape and muscular arrangement on the efficiency of force generation in individual muscles. The results show that this variation has a large effect on the force output of the muscles. First results indicate that musculature associated with the proximal region of the tail are able to generate higher forces than those of the distal region, but further analyses are required to confirm this.

95-6 Lunsford, ET*; Keene, AC; Liao, JC; Universtiy of Florida, Gainesville & Whitney Laboratory for Marine Bioscience, St. Augustine FL, Florida Atlantic University, Jupiter FL; *elunsford@ufl.edu*

Evolution of eye loss shapes lateral line sensitivity of blind cavefish during swimming: new insights from neurophysiology

Mexican blind cavefish (*Astyanax mexicanus*) have convergently evolved eye loss and heightened sensitivity of the lateral line system. Blind cavefish exhibit dramatic changes in lateral line-mediated behavior when compared to sighted surface fish. For the first time, we investigate the neurophysiological mechanisms of enhanced sensitivity and active-flow sensing. Electrophysiological recordings of posterior lateral line afferent neurons reveal that spontaneous activity is elevated in blind cavefish which suggest a lower threshold for lateral line signal transduction. In surface fish, like many fishes, there is an efferent system that cancels out self-generated flow stimuli during locomotion to stay receptive to biologically relevant stimuli. In contrast, cavefish do not have a fully functional efferent system because they rely on self-generate flow to navigate their environment. Afferent recordings reveal cavefish lateral line sensitivity is not modulated by efferent neurons during swimming. Targeted ablation of hindbrain efferent neurons in surface fish results in lateral line signaling similar to cavefish. Cavefish may either have functionally diminished efferent neurons or have evolved post-synaptic differences compared to surface fish. Our results suggest decreased

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functionality of efferent neurons. to enable active-flow sensing. has converged across three separate populations of cavefish.

103-2 Lutek, K*; Foster, KL; Znotinas, KR; Standen, EM; University of Ottawa, Ottawa, ON, Ball State University, Muncie, IN, Department of Fisheries and Oceans Canada, Vancouver, BC; *klute061@uottawa.ca*

Do environmental gradients elicit behavioural gradients in an amphibious fish

Many species of fish are capable of terrestrial locomotion. While these species often make use of specialized structures, many species can also perform effective terrestrial locomotion using the same set of locomotor tools (i.e. central pattern generators, musculoskeletal system, sensory systems) that are primarily adapted for an aquatic environment. Studies often look at locomotion in fully aquatic and fully terrestrial environments. However, this ignores the ecologically relevant transition between these environments and offers no opportunity to investigate whether terrestrial and aquatic locomotion in these species are distinct behaviours or a part of a continuum. Here, we test the hypothesis that the switch from swimming to walking is discrete in *Polypterus senegalus* by exposing fish to a series of environments spanning the aquatic-terrestrial transition. We report changes in kinematics, muscle activity and coordination of the two, focusing especially on environments in which environmental forces would shift from buoyancy-dominant to gravity-dominant. We show that while swimming and walking do appear to be distinct behaviours, *P. senegalus* use transitional behaviours in intermediate environments.

43-4 Luttbeg, B; Beaty, LE; Ambardar, M; Grindstaff, JL*; Oklahoma State University, Penn State Erie - The Behrend College, Fort Hays State University; *jen.grindstaff@okstate.edu*

Mathematical modeling reveals the speed of endocrine flexibility constrains baseline and stress-induced glucocorticoid levels

Unpredictable environmental changes displace individuals from homeostasis and elicit a stress response. In vertebrates, the stress response is mediated mainly by glucocorticoids (GCs) which initiate physiological changes while minimizing allostatic load.

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Individuals and species vary consistently in baseline and stress-induced GC levels and the speed with which GC levels can be upregulated or downregulated, but the extent to which variation in hormone regulation influences baseline and stress-induced GC levels is unclear. Using mathematical modeling, we tested how GC regulation rate, frequencies and durations of acute stressors, fitness functions, and allostatic load affect GC levels during control and acute stress periods. As GC regulation rate slows, baseline and acute stress-induced GC levels become more similar. When the speed of up- and down-regulation decreased, hormone levels became more linked to anticipated future conditions to avoid fitness costs of mismatching a new environmental state. When fitness was more tightly linked to hormone levels during acute stress periods than during control states, the speed of upregulation influenced optimal hormone levels more than downregulation rate. More frequent acute stressors caused baseline and acute stress-induced GC levels to converge. With allostatic overload costs included, predicted GC levels were lower and were more dependent on the frequency of past acute stressors. Our results show the value of optimality modeling to study the hormonal response to stressors and suggest GC levels depend on past and anticipated future environmental states, and individual differences in hormone regulation.

110-5 Lynch, LM*; Allen, KL; Midwestern University Glendale, Washington University in St. Louis School of Medicine; *llynch@midwestern.edu*

Carnivoran relative brain volume does not correlate with environmental and dietary variation

Among mammals, primates and carnivorans possess larger brains for their body sizes relative to other clades. Several factors, such as environmental complexity (Cognitive Buffer Hypothesis), degrees of sociality (Social Brain Hypothesis), and diet quality and metabolism (Expensive Brain Hypothesis) have been proposed as mechanisms for encephalization. While studied extensively in Primates, in Carnivora predominantly the Social Brain Hypothesis has been tested. We examine whether predictions made by the Cognitive Buffer and Expensive Brain Hypotheses account for variation in brain size among extant carnivorans. Under the

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Cognitive Buffer Hypothesis, we predict a positive correlation between brain size and environmental variation. Under the Expensive Brain Hypothesis, we predict brain size and meat consumption will be positively correlated. Relative endocranial volume (PGLS residual from species mean body mass) and 9 environmental and/or dietary variables were collected from the literature for 148 species of terrestrial carnivorans. Environmental data was sourced from GIS maps provided by WorldClim, North American Data Atlas, and NASA/GSFC. We found no significant relationship using PGLS regression between any of the environmental and dietary variables with relative brain volume. These results suggest that carnivoran brain volumes do not support the Cognitive Buffer nor Expensive Brain Hypotheses; however, we cannot rule out simultaneous effects of both hypotheses. The strong phylogenetic signal within brain volume and body size suggests that these traits are under some form of selection, which may differ among clades. Future analyses of individual carnivoran clades may, therefore, be more conclusive.

66-2 Lynch, J*; Gau, J; Sponberg, S; Gravish, N; University of California, San Diego, Georgia Institute of Technology; *jelynch@ucsd.edu*

Dimensional analysis reveals limits on peak efficiency of flapping wing flight due to structural damping

Hovering insects and birds across a wide range of sizes and morphologies, from tiny flies to hawkmoths and hummingbirds, are thought to achieve energy-efficient flapping flight by storing and releasing elastic energy in their muscles, tendons, and thoraxes. These disparate species all seem to operate in regimes where the ratio of inertial to aerodynamic power, N, is in the range of 1 to 10, suggesting that there is some constraint on the energetics of flapping outside of that range. We present an updated model of the dynamics and energetics of flapping flight that includes internal losses associated with structural damping within the insect thorax. Recent work has suggested that structural damping may be as high as 20% of the total energy loss in flapping insects, so it is necessary to understand the impact of such losses on the overall energetics of flapping systems. We perform dimensional analysis and numerical simulation and conduct physical experiments on a robotic flapping wing with tunable elasticity and structural damping. We

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find that any damping, even in small amounts, fundamentally changes the biomechanical parameter space in which flight has evolved. We show that the upper bound on dynamic efficiency, an important metric of the ability of a wing to transmit muscle effort, monotonically decreases with increasing *N* in any system that has non-ideal elastic storage, potentially explaining the somewhat narrow range of *N* in hovering insects and birds. This detailed non-dimensional formulation of the dynamics and energetics of flapping flight is valuable both for understanding the evolution of insect flight biomechanics and for the future design of flapping-wing micro-robots.

108-8 Lyons, AM*; Roberts, KT; Byassee, P; Williams, CM; University of California, Berkeley; *lyonsa@berkeley.edu*

Sensitivity of tardigrades (Hypsibius exemplaris) to ecologically relevant cold

Tardigrada are a distinct evolutionary lineage of microscopic aquatic animals that may utilize novel physiological mechanisms for stress response. Past research explored tardigrades' extreme stress tolerance, but little is known about the phylum's sensitivity to ecologically relevant cold. Here, we use *Hypsibius exemplaris*, a cosmopolitan species, to characterize the physiological response to low temperatures experienced in nature. We monitored performance and survival of *H. exemplaris* over a range of acute exposure times and temperatures. Tardigrades entered chill coma after 12h at 1° C. Response to exposure time depended on temperature: above -1° C, chill coma recovery times decreased with duration of exposure, suggesting acclimation. Below -1° C to -4° C, increasing exposure time extended recovery times, suggesting accumulation of sub-lethal damage. To explore freezing temperatures, we developed an assay using SYTOX Green to stain for cell death—facilitating accurate and high-throughput differentiation of thousands of live, dead, and injured tardigrades. Hydrated tardigrades exposed to -10° C show low mortality, even after 120h. Tardigrades exposed to -20° C froze and accumulated damage within 2h, with 50% mortality after ~24h. Interestingly, experimentally induced ice-nucleation at -10° C did not result in SYTOX Green uptake after 120h, suggesting environmental ice formation alone does not result in mortality. This work suggests that *H. exemplaris* is sensitive to ecologically

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relevant cold and established highly reproducible assays for cold tolerance in an emerging non-model system, useful for exploring additional tardigrade species. Evidence suggests that *H. exemplaris* may rely on freeze tolerance, guiding exploration of underlying molecular mechanisms.

69-5 Lyons, KM*; Heck, K; Fercak, O; Haddock, WA; Cal, RB; Martin, WN; Murphy, CT; Franck, JA; University of Wisconsin-Madison, Portland State University, Brown University, Portland State University, US Navy; *lyons6@wisc.edu*

The effect of wavelength in seal whisker undulations

Harbor seals, among other true seal species, have uniquely undulated whiskers that allow them to track their prey using hydrodynamic trail following. The effects of the complex topography in reducing drag and vortex-induced-vibration (VIV) have been previously observed and documented. However, a more thorough analysis of the effects of deviations from nominal topography values offers an opportunity to assess a range of applicability, flow mechanisms, and a potential for interspecies comparison as well as a basis for bioinspired engineering design. This investigation employs dye visualization to examine the flow over a 3D-printed seal whisker and three additional models with the same nominal parameters as the seal whisker but with a range of undulation wavelength values. Experiments are performed in the Naval Undersea Warfare Center water flume at two different biologically relevant Reynolds numbers. Computer vision techniques are used to analyze the frequency content from vortex shedding and the downstream wake width, as a function of wavelength. Compared to the other wavelengths, a marked shift in frequency content is extracted from analysis of the seal whisker model, which is correlated with the shedding of vortical structures. The frequency, size, and shape of the vortical structures also decrease the width of the downstream wake. The experiments are supported by direct numerical simulations (DNS) of the same geometries, which enable a time-resolved and three-dimensional flow-field of vortex shedding.

77-4 Macias-Muñoz, A*; Picciani, N; Murad, R; Mortazavi, A; Oakley, TH; University of California, Santa Barbara, University of

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How much convergence exists in vision-related genes of independently evolved eyes in Cnidaria?

Convergently evolved traits act like replicates in the singular history of life, allowing biologists to ask whether evolution follows similar or different paths to similar end points. One such trait is animal eyes, which evolved convergently numerous times, and therefore could allow biologists to understand whether evolution took similar genetic paths to evolving eyes repeatedly. However, beyond a few specific candidate genes, not much work has been done investigating convergence versus divergence of genes expressed in convergently evolved eyes. This research is important because it can parse the roles of gene duplications, protein coding mutations, gene regulation, and co-option in convergent evolution. A unique group in which to study convergent evolution is Cnidaria because eyes evolved convergently multiple times within Medusozoa (jellyfish). Furthermore, eyes are an excellent trait for studying genetic evolution because scientists know a lot about genetic mechanisms like phototransduction, especially in model systems. We used genomics and transcriptomics to characterize the molecular evolution and expression of candidate phototransduction genes in three cnidarian species: *Hydra vulgaris*, which lack eyes but exhibit light-dependent behavior, and two species with convergently evolved eyes *Tripedalia cystophora* and *Aurelia aurita*. Results from this study show that while many homologous genes annotated with phototransduction functions are upregulated in the eyes, many components vary by eye origin. Therefore, despite common claims in evo-devo for master regulatory genes and deep homology, we find many genes to be specific to convergently evolved eyes, indicating that evolution may often take different paths to similar end points.

111-4 MacKenzie, EM*; McKinnell, I; Maddin, H; Earth Sciences, Carleton University, Ottawa, ON, Canada, Biology Department, Carleton University, Ottawa, ON,
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Influence of brain-skull interactions in the evolution of the amphibian skull

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The tetrapod skull is a vastly diverse structure due to complex interacting factors including phylogeny and development. In amniotes, it is known that brain expansion has influenced skull evolution wherein cranial vault expansion correlates with cerebral hemisphere expansion. However, the molecular basis for this correlation, and whether such a correlation exists in non-amniotes, has not been solidified. Previous research has proposed that the resulting skull bones are spatially related to the embryonic brain at its 3-vesicle stage, with the frontal bone developing in tandem with the forebrain. To understand the interaction at a molecular level, our research aims to conduct knockdown experiments for key regulatory genes of forebrain development in *Xenopus laevis* and *Ambystoma mexicanum*. These two species were chosen for their differing cranial proportions (i.e. *X. laevis* has a shorter frontal [part of the frontoparietal], whereas *A. mexicanum* has a longer frontal) and for their potentially correlated proportions of the developing brain. Our hypothesis is that if key forebrain regulatory genes are inhibited during early developmental stages, then the resulting frontal bone development should also be affected, confirming a gene level interaction. In addition, we will conduct forebrain transplants between the two species before the forebrain tissue becomes committed to its developmental fate. If the forebrain tissue is communicating directly with the skull, then the resulting skull should resemble that of the transplanted species. These results will yield novel data on amphibian brain developmental genetics as well as revealing an underexplored aspect of tetrapod skull evolution - the brain.

BSP-9-2 MacNeill, BN*; Straub, SK; Ivey, EP; Brewer, KZ; McKain, MR; The University of Alabama, Hobart and William Smith Colleges; *bnmacneill@crimson.ua.edu*

Resolving relationships within the genus Amorpha using whole chloroplast genomes

The genus Amorpha is a North American endemic in the family Fabaceae comprising ~20 species. The genus is characterized by the absence of the floral keel and wing found in most papilionoid legumes, dramatic morphological variation, and the ability to occupy various habitats. A. fruticosa has the broadest range of all species encompassing the distribution of the genus. The majority of

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other Amorpha taxa occur in various habitats, including riparian corridors, prairies, and savannas. A. fruticosa has at least 39 synonyms, suggesting taxonomists have noticed enough morphological variation in this species to merit the naming of new taxa. This taxonomic confusion leads us to question if A. fruticosa is a single species with high morphological plasticity, or if hybridization between species results in novel morphologies or preference for diverse and novel habitats. Using a combination of morphological analysis, ecological niche modeling, and whole-chloroplast genome sequencing for 80 accessions of Amorpha, we address these questions focusing on A. fruticosa, A. glabra, A. nitens, and A. schwerinii, the primary species of Alabama. Our data suggestA. fruticosais non-monophyletic and morphologically diverse. We also describe population-level chloroplast diversity across the southeastern US with a focus on identifying novel chloroplast haplotypes. The chloroplast phylogeny will further elucidate the relationships of this genus and allow us to develop a better understanding of species diversity, not just across the Southeast, but in general, for morphologically diverse species, like A. fruticosa

42-3 Madelaire, CB*; Dillon, D; Barsotti, AMG; Measey, J; Gomes, FR; Buck, CL; Northern Arizona University, University of São Paulo, Stellenbosch University, University of São Paulo; *cmadelaire@yahoo.com.br*

Corticosterone levels in the saliva as a measure of stress in toads

Glucocorticoids have been widely used as a physiological marker of stress, and elevated baseline glucocorticoids levels in vertebrates have been associated with environmental changes. The use of minimally invasive sampling techniques and analysis of non-traditional sample types to monitor stress in wild populations has increased due to the importance of understanding how animals respond to environmental disturbances. The use of saliva samples can be a powerful tool to monitor both endocrine shifts and responses to stressors in wild populations. This sampling method does not require a large amount of manipulation and it can be used to sample smaller species, contributing to an increase of studies in environmental endocrinology and conservation efforts of

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understudied species. This study validated corticosterone (CORT) measurements in the saliva of the guttural toad (*Sclerophrys gutturalis*) using samples collected in the field and after a standardized stress protocol. We show that small amounts of saliva (0.018±0.028 g) are sufficient to quantify CORT. Salivary CORT levels were higher after exposure to a standardized stress protocol when compared to field levels of CORT, indicating that saliva samples can reflect biologically meaningful levels of CORT in the guttural toad. Because levels of salivary and plasma CORT were not correlated in either the field sampled animals or following exposure to acute stress, we conclude that CORT in the saliva and plasma might show different response dynamics to stimuli.

66-3 Maeda, M*; Walker, SM; Fabian, JM; Siwanowicz, I; Lin, HT; Bomphrey, RJ; Royal Veterinary College, Hatfield, UK, University of Leeds, Leeds, UK, Flinders University, Adelaide, South Australia, Australia, HHMI Janelia Research Campus, Ashburn, VA, Imperial College London, London, UK; *mmaeda@rvc.ac.uk*

Numerical simulation of high-fidelity dragonfly wings for "Fly-by-Feel"

The wings of flying animals undergo large, periodic deformations during flight due to aerodynamic and inertial loads. Insect wings express a sparse array of mechanosensors sensitive to strains and airflows, allowing rapid monitoring of local loads and wing aerodynamic state. Our goal is to discover how insects perceive mechanosensory information and use it to control flight. We use dragonflies as a model because they have excellent control in both gliding and flapping flight. Here, we present numerical simulations of a gliding dragonfly with high-fidelity wing geometries that flex under aerodynamic loads. To solve for the wings' aeroelastic responses, computational structural dynamics (CSD) and computational fluid dynamics (CFD) solvers are loosely coupled. We also present CFD results of a flapping dragonfly in free flight, using our high-fidelity wing models, but with prescribed kinematic deformations. There are three advances: i) a high-fidelity wing model containing detail of micro-structural ridges, valleys and vein cross-sectional geometries, acquired using a hybrid approach of micro-computed tomography and stereo photogrammetry; ii) a demonstrated capacity for fluid-structure interaction (FSI)

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modelling using commercial code; iii) acquisition of accurate, deforming-wing, flapping kinematics, including wing twist, from freely flying dragonflies using nine, synchronised high-speed cameras. The resulting flow fields and strain fields on the wing surfaces are examined to see how the distributed sensors would observe discrete data for flight control.

23-3 Magondu, B*; Cervantes, G; Lee, A; Kaminski, C; Yang, P; Carver, S; Hu, D; Georgia Institute of Technology, University of Tasmania; *bmagondu3@gatech.edu*

How the vombatus ursinus forms cubic feces, with an application to the feces of terrestrial mammals

The *Vombatus Ursinus*, or the common wombat is known for its cubic feces with six flat faces. In previous work, we showed that wombats form square cross-sections due to the non-uniform material properties of their intestine. In this study, we focus on the remaining two faces of the cube. We mimic wombat feces formation by performing experiments with drying cornstarch slurry in one-dimensional troughs. Cracks naturally form perpendicular to the walls, and with a crack spacing proportional to the trough width. We present a numerical model of this phenomenon, accounting for the diffusion of water through the porous corn starch, which generates dry regions and initiating cracks. We apply our rationale to predicting the size of fecal matter in terrestrial animals, such as rats, gerbils, rabbits, and goats, as a function of moisture content.

39-5 Maher, AE*; Cox, PG; Maddox, TW; Bates, KT; University of Liverpool, Institute of life course and medical sciences, Liverpool, UK, University of York, Department of Archaeology and Hull Medical York School,York, UK , University of Liverpool, Institute of Infection, Veterinary and Ecological Sciences, Small Animal Teaching Hospital, Leahurst Campus,Neston, UK; *A.E.Maher@liverpool.ac.uk*

The evolution of body shape in terrestrial tetrapods

Body shape plays a fundamental role in organismal function and it is expected that animals will evolve body proportions that best exploit their ecological niche. Terrestrial tetrapods have evolved

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a disparate array of body plans over the past 350 million years, but to-date this diversity in body shape and its relationship to ecology and behaviour have not been systematically quantified. Here we analyse body proportions in 411 extinct and extant terrestrial tetrapods spanning most major taxonomic, locomotor and dietary groups. We show that most body segments scale with negative allometry across terrestrial tetrapods as a whole but find statistical support for quadratic relationships that suggest differential scaling in small-medium versus large animals. Statistical analyses of shape differences and allometric trends in different locomotor and dietary groups highlight key adaptations in body proportions that mechanistically underlie the exploitation of key ecological niches, such as flight and hyper carnivory, as well revealing patterns of changing body proportions during major macroevolution events, such as bipedal-quadrupedal transitions. Overall, our results emphasise that changing body proportions played an important role in the broad-scale ecological diversification of terrestrial tetrapods.

59-1 Mainwaring, MC*; Martin, TE; Wolf, BO; Tobalske, BW; University of Montana, University of New Mexico; *mark.mainwaring@mso.umt.edu*

Direct sunlight reduces the cost of keeping altricial avian offspring warm

Parental care is often energetically expensive and keeping offspring within acceptable thermal limits may be particularly costly for endotherms in temperate and sub-tropical regions where spring temperatures are below thermoneutral zones. We sought to test whether higher temperatures in the arid tropics may mitigate the energetic demands of keeping avian offspring warm, as this possibility remains largely unexplored. Passerine birds develop optimally at ~37-39°C and birds in tropical dry forest may experience temperatures close to, or exceeding, 39°C. We also sought to test the effects of nest architecture on thermal requirements for breeding birds in tropical Ecuador. Adults can potentially modify nest temperatures by building enclosed, rather than open, nests if enclosed nests offer greater insulation. Using custom-built circuits, we measured the power required to maintain 39°C. Nest temperatures were usually close to, and often exceeded,

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39°C in open cup nesting species, but not in an enclosed nesting species. Experimental shading of nests resulted in nest temperatures only rarely exceeding 39°C in species with either open or enclosed nests. Further, shading meant that the power required to keep a nestlings warm was significantly increased. We demonstrate that high temperatures may be beneficial for the heat balance of tropical birds up to a point. Radiant heat from direct sunlight causes temperatures inside birds' nests to be critically high (up to ~ 46°C) for birds breeding tropical dry forest, but when nests were shaded from direct sunlight, they only rarely experienced such critically high temperatures. This suggests, however, that nest-site selection at the micro scale can enable adult birds to mitigate the effects of lethally high temperatures upon nestlings. (NSF: IOS: 1656120).

24-9 Maisonneuve, MC*; Schiebel, PE; Diaz, K; Goldman, DI; Georgia Institute of Technology, Harvard, Georgia Institute of Technology , Georgia Institute of Technology ; *mmaisonneuve3@gatech.edu*
Passive environmental navigation via mechanical interactions in a novel snake robophysical model
Limbless animals generate and propagate waves along their body to move in complex terrains. Specifically, snakes rely on alternating unilateral muscle activation for locomotion [Jayne, J.*Morph.*, 1988]. Previously studied desert specialist snake [Schiebel et al.,*PNAS*, 2019], *C. occipilatis* , relies on passive body buckling aided by unilateral muscle activation to negotiate and overcome obstacles. Inspired by those experimental results, we developed a robophysical model, measuring 63cm in length and 8cm width, that models snake muscle morphology and activation patterns. The robot consists of 8 joints, each composed of a two motor pulley system. Each joint is actuated by having a pair of motors on one side spool while the opposite side is completely unspooled generating no tension. Joints were programmed to be unilaterally active, propagating a sine wave along the body of the robot. We performed wall collision experiments, where the robot would collide head-on with a low friction surface. Upon collision, the robot passively buckled, similarly to the snake, causing an increase in the body wave amplitude and changing its orientation to resume motion. Further, we performed experiments in a hexagonal lattice, a

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simplified heterogeneous terrain. The robot exhibited two behaviors to overcome jams and traverse the lattice. As in the wall collision experiments, we observed passive buckling that allowed the robot to reorient itself and to progress around an obstacle. In addition, we observed a reversal behavior that allowed the robot to overcome jams when the nominal waveform was perturbed. Our results suggest that as in legged devices, obstacle negotiation in limbless locomotors can be enhanced by offloading control to mechanical design, without relying on external sensing of the environment.

62-6 Malinski, KH*; Kingsolver, JG; Willett, CS; University of North Carolina, Chapel Hill; *malinski@live.unc.edu*
Thermal mismatch in an insect host-parasitoid-endosymbiont system: causes and consequences
While differential thermal tolerances among interacting species have been documented in various systems (e.g. coral bleaching, ant microbiomes), the causes and consequences of this thermal mismatch have rarely been explored in complex multitrophic systems. Here we investigate the three-way interaction among an insect host (*Manduca sexta*), its insect parasitoid (*Cotesia congregata*), and the parasitoid endosymbiont (*C. congregata* bracovirus, CcBV). Recent studies found that the parasitoid has a lower thermal tolerance than its host; parasitized *M. sexta* tolerate heat-shock temperatures lethal to *C. congregata*. It is unclear whether parasitoid mortality is caused by heat directly (hypothesis 1), or by heat-induced disruption of host immunosuppression by CcBV, leading to parasitoid death via recovered host immune response (hypothesis 2). To test these hypotheses, we compared levels of immune response in parasitized and unparasitized *M. sexta* larvae under heat-shock and control temperatures. Preliminary results are consistent with hypothesis 2, indicated by a heightened immune response in the parasitized, heat-shocked group relative to the parasitized control group. This study contributes to the understanding of thermal mismatch, a critical step in predicting organismal and system-level responses to climate change.

34-5 Malkoc, K*; Casagrande, S; Hau, M; Max Planck Institute for Ornithology, DE; *kmalkoc@orn.mpg.de*

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Inferring whole-organism metabolic rate from red blood cells? Yes, in non-stressed birds

Metabolic rate (MR) quantifies the 'rate of living' of aerobic organisms and represents a fundamental physiological measure used in many ecological and evolutionary studies. MR is typically measured in intact organisms confined in measurement chambers for long periods of time (respirometry). It is a well-established technique and can record real-time O_2 consumption. However, prolonged confinement may be stressful for individuals, increasing stress hormone concentrations and certain behaviors, thereby biasing MR measurements. Recently a technique to measure MR in blood cells became available, opening the possibility to assess MR in free-living and/or vulnerable individuals while minimizing exposure to stressful conditions. Yet it has remained unclear whether MR recorded in blood cells yields comparable information as traditional respirometry. We took both measures in captive great tits (*Parus major*) by collecting a blood sample before and after 2.5 hrs of respirometry during daytime. The two blood samples allowed us to record red blood cell MR and plasma corticosterone concentrations, while respirometry and video recordings monitored locomotor activity and whole-organism MR. Many individuals had high, stress-induced concentrations of corticosterone. Corticosterone concentrations were positively associated with locomotor activity, suggesting that both parameters reflect individual stress levels. Importantly, whole-organism and red blood cell MR were positively correlated only in individuals with low corticosterone concentrations. Our results indicate that red blood cell MR is a suitable alternative to respirometry if subjects are not stressed. They also highlight the importance of accounting for physiological and behavioral responses of individuals during respirometry.

66-7 Mamo, AH*; Weber, AI; Mohren, TL; Babaei, M; Daniel, TL; University of Washington, Carnegie Mellon University; *aiweber@uw.edu*

Finite element analyses of flapping wings meets inertial sensing

Insect wings act not simply as actuators, generating the forces necessary for flight, but also act as sensory structures that provide rapid feedback for stable flight control. Wing structural

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mechanics and motions determine wing strains and therefore neural signals conveyed by sensory structures. Prior studies of sensing in flapping wings relied on analytical models based on Euler-Lagrange equations. Although these approaches are computationally tractable, they preclude more complex structures and kinematics associated with real wing motions. Here, we developed a finite element model that allows us to investigate sensing in the context of more realistic wing structural mechanics and movements. We developed a simplified model that shares several features with wings of the hawkmoth *Manduca sexta* and our prior analytic models of a flapping plate subject to rotation orthogonal to the flapping motion. The model simulates the spatial and temporal pattern of strain over the wing. That strain is then encoded by a neural-inspired transform which includes a linear filter and non-linear threshold to predict spatial and temporal patterns of neural spiking. We then used that spiking pattern, along with a compressive sensing algorithm to show that we can detect body rotations of comparable magnitude to those experienced by *Manduca* during flight with greater than 95% accuracy with only five sensors. This framework allows us to incorporate a variety of wing structural properties and kinematics, and to investigate sensing in the context of biologically realistic wings.

BSP-2-8 Manafzadeh, AR*; Gatesy, SM; Brown University; *armita@brown.edu*

All six degrees of freedom are essential to reconstructions of articular function

Paleontologists often reconstruct organismal function by estimating joint range of motion (ROM) and excluding behaviors that require impossible joint poses. This "ROM-based exclusion" has been considered conservative because it is thought that manipulations of bones overpredict true ROM. However, some analyses have concluded that they might actually underpredict true ROM, meaning that viable joint poses might erroneously be excluded from functional reconstructions. Our goal was to test the validity of ROM-based exclusion with data from the main hindlimb joints of the Helmeted Guineafowl (*Numida meleagris*) and the American alligator (*Alligator mississippiensis*). We first estimated the rotational mobility of each joint using CT-derived bone models. We then compared these estimated mobilities to each joint's true ROM, as measured from

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an *ex vivo* marker-based X-Ray Reconstruction of Moving Morphology study. We found that even when we allowed interactions among all three rotational degrees of freedom (DOF), we still failed to capture all possible cadaveric poses. Therefore, we developed an automated method for incorporating interactions among all six DOF at each joint. Only when we implemented this new method did our "paleontological" ROM estimates succeed in capturing the full cadaveric ROM of all joints studied. We thus conclude that all six DOF are essential to reconstructions of articular function - and as a result, that existing functional interpretations founded on ROM-based exclusion must be re-evaluated to determine if their inferences still hold when joint translations are incorporated. More broadly, this work counters the assumption that joint translations are minimal and therefore negligible. Moving forward, we must measure and explore interactions among all six DOF to advance our understanding of how joints work.

S9-5 Mangiamele, LA; Smith College; *lmangiamele@smith.edu*
Androgenic modulation of multimodal signal structure in foot-flagging frogs
Multimodal communication requires coordination of multiple signaling systems. Yet, how multiple signaling traits arise, interact, and share (or do not share) underlying mechanisms is not well understood. In the frog *Staurois parvus*, visual, vocal, and gestural signals are used for sexual communication in a noisy streamside environment. The recent evolution of "foot flagging" - a gestural signal involving extension and backward rotation of a hind leg - is associated with increased sensitivity to androgenic hormones in the main muscles controlling limb movement, similar to that found in the larynx of vocalizing frogs. We therefore hypothesized that multiple male signals would be androgen dependent in *S. parvus*. However, antagonism of both central and peripheral androgen receptors (ARs), or peripheral ARs alone, inhibits foot flagging but it does not affect vocalization. Further, antagonism of ARs also decreases the number of transitions between unique display components in a multimodal signaling bout. Together, these results suggest that androgenic action may play a role in overall mating display architecture or signaling strategy, possibly

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underlying the ability to switch signaling modalities in different environmental or social contexts.

S12-9 Manica, LT*; Schaedler, LM; Ribeiro, PHL; Universidade Federal do Paraná, Departamento de Zoologia, Curitiba, Brazil, Instituto Nacional de Pesquisas da Amazônia, Programa de Pós-graduação em Ecologia, Manaus, Brazil , Universidade Federal do Paraná, Programa de Pós-graduação em Zoologia, Curitiba, Brazil; *lilianmanica@gmail.com*

A manakin of many friends: unveiling the multi-male cooperative displays of the Swallow-tailed Manakin

Courtship displays result from sexual selection acting upon variable and heritable traits in a high reproductive skewed population, a typical scenario found in lekking species. In this regard, manakins are iconic Neotropical forest birds for producing elaborated dances with their colorful plumage. The Swallow-tailed Manakin is a highlight in the Atlantic Forest for its multi-male dance in a cartwheel-like flight. We reviewed the current knowledge on this species and show advances of a five-year study on coloration variability, and motor and acoustic traits. We sampled feathers and courtship behavior of banded males in south Brazil. Using videos of cooperative and solo displays, we found nine male motor elements. Transitions between these elements were stereotyped, although variability among courts was significant and dependent upon male social status. Vocalization was also variable within the dance, speeding up towards the end, in coupled synchrony with accelerating flight movements. Using phenotype networks, we found the social context (i.e., female presence) influences the display-plumage traits relationship. These results reveal an important background to upcoming studies on how sexual selection acts upon populations of this species. Towards this aim, we are currently focused on within-male and within-court consistency during the dance to test for their impact on female decisions in accepting copulation.

BSP-1-1 Manka-Worthington, SE*; Hews, DK; Indiana State University; *sworthington1@sycamores.indstate.edu*

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Perinatal hormones and offspring dispersal in the ovoviviparous Sceloporus jarrovii lizard

Maternal steroid hormones can affect offspring dispersal, as has been found in *Lacerta vivipara*, a live-bearing species. We examined this in *Sceloporus jarrovii*, a distantly-related ovoviviparous lizard. To understand associations of maternal corticosterone (CORT) with offspring dispersal behavior, we measured maternal CORT at time points prior to and after parturition, and also recorded newborn movements in large outdoor natal arenas. Maternal plasma CORT levels decreased after parturition. Offspring associated with dams and with each other after birth, then exhibited potential dispersal behavior starting on Day 6 after birth. Pups maintained associations with littermates until at least Day 14 after birth. Offspring of females with highest prenatal CORT dispersed soonest, around Day 4 after birth. In a second field season, we manipulated late-gestation maternal CORT levels using implants. Again, we found that apparent offspring dispersal was earlier in offspring of CORT-implanted dams, relative to offspring from control-implanted females. Higher maternal CORT levels may reflect stressful environments. This supports the hypothesis that earlier offspring dispersal from stressful environments may be mediated by higher prenatal maternal CORT levels. Future work should examine environmental factors contributing to variation in maternal CORT levels.

2-4 Mao, TR; Liu, YW; Meegaskumbura, M*; Ellepola, G; Fu, CH; Gross, JB; Pie, MR; Guangxi University, University of Cincinnati, Universidade Federal do Paraná; *madhava_m@mac.com*

Evolution in Sinocyclocheilus cavefish is marked by rate shifts, reversals, and origin of novel traits

Sinocyclocheilus of China, the most diverse cavefish clade in the world (75 species), provide unique opportunities to understand recurrent evolution of stereotypic traits. However, they remain poorly understood in terms of morphological evolution. We constructed phylogenies and categorized 49 species based on eye-related condition (Blind, Micro-eyed, and Normal-eyed), habitat types (Troglobitic - cave-restricted; Troglophilic - cave-associated; Surface - outside caves) and existence of horns. Geometric-morphometric analyses show Normal-eyed morphs with

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fusiform shapes segregating from Blind/Micro-eyed deeper bodied morphs (1st PC axis); 2nd PC axis accounts for shape complexity related to horns. Ancestral reconstructions suggest at least three independent origins of Blind morphs, each with different levels of modification in relation to their ancestral Normal-eyed morphs; *Sinocyclocheilus* are also pre-adapted for cave dwelling. A geophylogeny shows an east-to-west diversification spanning Pliocene and Pleistocene, with Troglobitic species dominating karstic plains and Surface forms inhabiting western hills. Evolutionary rates analyses suggest that lineages leading to Blind morphs were characterized by significant rate shifts, such as a slowdown in body size evolution and a 3-12 fold increase in rate of eye regression, possibly explained by limited resource availability. Body size and eye size have undergone reversals, but not horns, a trait entailing considerable time to form.

97-2 Marcé-Nogué, J*; Liu, J; Universitat Rovira i Virgili, Tarragona, Institut Català de Paleontologia Miquel Crusafont, Barcelona and University at Buffalo, NY, University of California, Berkeley and University at Buffalo, NY; *jordi.marce@urv.cat*

Biomechanical and morphological fidelity of CT based 3D models for Zebrafish conductive hearing system

The aim of this work is to evaluate computational models generated from multiple μCT scans with different parameters, to identify the most feasible scan combination for practical (minimized scan time) yet accurate (relative to highest resolution) biomechanical simulations. We segmented Weberian ossicle chains of Zebrafish and created 3D models from CT scan image stacks at 4.64 μm, 5.05 μm, 9.30 μm and 13.08 μm voxel resolutions. We used geometric morphometrics analysis to quantify inter-model shape differences and finite element modal and harmonic analyses to simulate auditory signal vibrations. Relative to the highest resolution and most accurate model, the Model 9.30 is closest in overall geometry and biomechanical behavior of all lower resolution models. We note that the differences in resolution (model 13.08) and quality (model 5.05) of the CT substantially affected the segmentation, reconstruction process and results of the 3D model of the ossicles. Therefore, we conclude that scan voxel resolution and contrast variations in CT images are a key factor influencing the results

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obtained in biomechanical simulations of delicate and minute structures.

26-5 Marguerite , NT*; Bernard, J; Harrison , DA; Harris, D; Cooper, RL; University of Kentucky, 520 Ruddles Mill Rd, Paris, KY; *Nicole.Marguerite@uky.edu*

Effect of temperature on heart rate for Phaenicia sericata and Drosophila melanogaster with altered expression of the TRPA1 receptors

The transient receptor potential (TRPA - ankyrin) receptor has been linked to pathological conditions in cardiac function in mammals. To better understand the function of the TRPA in regulation of the heart function the Drosophila melanogaster model was used to express TRPA in heart and body wall muscles. Heartbeat of intact larvae as well as hearts in situ, devoid of hormonal and neural input indicate that strong activation of larvae over expressing TRPA at 30 or 370C stopped the heart from beating, but in a diastolic state. Cardiac function would recover upon cooling and short exposure to high temperature. Parental control lines increased heart rate transiently at 300C and 370C and, the heart rates at 370C would slow down within 3 minutes for in-situ vs in-vivo preparations. The in-situ preparations maintained an elevated rate at 30C. The heartbeat in the TRPA expressing line could not be revived at 370C with serotonin. Thus, TRPA activation may have allowed enough Ca2+ influx to activate K(Ca)+ channels into a form of diastolic stasis. TRPA activation in body wall muscle confirmed a depolarization of membrane. The Phaenicia sericata blow fly increased heartbeat at 30 and 370C and did not cease beating as compared to the Drosophila control lines. Over expressing TRPA in Drosophila and maintaining them at 370C would result in death within 24 hours whereas the blow flies thrived.

S9-2 Markham, MR*; Nourbakhsh-Rey, M; Wiser, SD; Maltby, RC; University of Oklahoma; *markham@ou.edu*

Multiple hormonal pathways modulate active sensory and communication signals in weakly electric fish

Nocturnal weakly electric fish generate electric organ discharges (EODs) to image their surroundings and communicate in darkness.

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Some species, known as pulse fish, generate EODs at 20-120 Hz with long irregular intervals while species known as wave fish produce EODs at regular uniform intervals with frequencies as high as 2000 Hz. Modulations of EOD rate and waveform convey or reveal important information to conspecifics during social interactions. Changes in EOD rate are controlled centrally through regulation of the pacemaker or command nuclei that coordinate action potentials in the electric organ cells (electrocytes) to produce the EOD. We focus here on changes in EOD amplitude and duration that are ultimately regulated by hormones that target electrocyte action potential characteristics. These changes occur over timescales ranging from minutes to days in response to prevailing organismal, environmental, and social conditions. Multiple hormones, including melanocortin peptides, leptin, and steroid hormones, exert direct and sometimes interactive effects on the electrical properties of electrocytes to produce corresponding changes in EOD waveform. Comparisons between pulse and wave fish reveal both common endocrine mechanisms of EOD waveform regulation as well as important differences that are potentially a function of differences in life history.

S7-6 Marks, MS; Children's Hospital of Philadelphia and University of Pennsylvania; *marksm@pennmedicine.upenn.edu*

Melanosome protein contents and oculocutaneous albinism: The importance of remaining neutral

Melanins in mammals are critical for photoprotection of the hair and skin and for proper retinal development and function. Melanins are synthesized within skin and eye pigment cells within specialized lysosome-related organelles called melanosomes. Defects in melanosome maturation or contents result in oculocutaneous albinism (OCA), characterized by hypopigmentation of the hair, skin and eyes, poor visual acuity, and additional ocular symptoms. Non-syndromic albinism results from defects in at least eight distinct genes, most of which encode melanosome membrane proteins. Several of these are key enzymes in melanogenesis, including tyrosinase (TYR), TYRP1 and DCT (mutated in OCA type 1, 3 and 8). Two others - OCA2 and SLC45A2 (targeted in OCA types 2 and 4) - are ion permeases that help neutralize the low pH of immature melanosomes as they mature within melanocytes. This neutralization is required

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for the pH-sensitive TYR to become active and initiate melanin synthesis. The products of several other more broadly expressed genes, including the chloride channel CLCN7 and the cation channel TPC2, are also disrupted in pigmentary disorders and appear to directly control melanosome pH. In addition, genetic analyses of skin pigment variation among African populations have identified additional genes whose products might indirectly influence melanosome ion content or pH, such as the lysosomal transporter MFSD12. These observations highlight the importance of controlling the ionic environment of melanosomes (and lysosomes) to neutralize the acidic pH of melanosome precursors and thereby support melanin synthesis.

17-5 Marks, JR*; Lailvaux, SP; Beatty, AE; Schwartz, TS; University of New Orleans, Auburn University, Auburn University; *jrmarks@my.uno.edu*

Effect of sprint training on Insulin-like Growth Factor 1 and Insulin-like Growth Factor 2 expression in green anoles (Anolis carolinensis)

The ecomorphological paradigm states that a deterministic relationship exists between structure and function with regard to whole-organism performance capacities such as locomotion. Consequently, increasing functional demand should elicit changes in the underlying physiological and morphological pathways supporting that function. Previous research in green anole lizards showed that exercise training alters a variety of physiological and morphological characteristics of trained individuals, yet the specific molecular pathways that are upregulated to effect these changes are poorly understood. The insulin/insulin-like signaling (IIS) network, a highly conserved environmental sensing network that mediates growth and metabolism, is a likely regulator of muscle development and metabolism in response to increased anaerobic activity. Two of the primary hormones of this network are insulin-like growth factor (IGF) 1 and IGF2. IGF1 is an important catalyst for cellular growth, but IGF2 has been significantly understudied in adulthood. In this experiment, we sprint trained green anole females (*Anolis carolinensis*) for six weeks, thereby forcing them to increase allocation of energy resources to muscle growth. We tested the hypothesis that *IGF1* and *IGF2* expression are

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both upregulated in sprint trained animals because IGFs are important regulators of cellular reproduction and ultimately skeletal muscle growth. Specifically, we predicted that *IGF1* and *IGF2* hepatic gene expression would be upregulated in sprint trained lizards compared to untrained control animals. These results contribute to our understanding of the IIS network in general, and shed new light on the role of IGF2 in particular in regulating physiological plasticity in reptiles.

44-5 Marroquin-Flores, RA*; Paitz, RT; Bowden, RM; Illinois St U; *ramarro@ilstu.edu*

Decoupling the effects of thermal and hormonal stimuli on intron retention in a species with temperature-dependent sex determination

The red-eared slider turtle (*Trachemys scripta*) exhibits a form of temperature-dependent sex determination (TSD) where exposure to either warm or cool temperatures induce female or male development, respectively. Under constant male producing temperatures, expression of *Kdm6b* (a histone demethylase) is induced and subsequently initiates testis development by demethylating at the promoter of *Dmrt1*. Under constant conditions, *Kdm6b* also displays differential intron retention (IR) where an intron is retained at cool temperatures. Here, we examine *Kbm6b* expression and IR using ecologically relevant conditions, where embryos are transiently exposed to male and female producing temperatures and show that short exposures to female producing conditions (i.e. heatwaves) eliminates IR in *Kdm6b*. IR and non-IR *Kdm6b* transcripts were quantified following exposure to a five-day heatwave at female producing temperatures (29.5 ± 37° C) and compared to embryos incubated under male producing temperatures (25.5 ± 3° C). Exposure to heatwaves resulted in a 10-fold reduction of *Kdm6b* IR transcripts after only 48 hours of exposure. We then set out to examine whether this effect was driven by thermal cues or underlying hormone signaling. To test this, exogenous estrogens were applied to eggs to induce ovarian differentiation in embryos incubating at male producing temperatures. We are generating expression profiles for *Kdm6b* in eggs under male, female, and sex-reversed conditions. This study represents the first time that

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fluctuating temperatures and hormones have been used in concert to characterize the expression of a TSD candidate gene.

53-8 Marshall, CA*; Zeller, KR; Kane, EA; Vincent, J; Angeloni, LM; Ghalambor, CK; Colorado State University, University of Louisiana at Lafayette, Norwegian University of Science and Technology and Colorado State University; *Craig.Marshall@colostate.edu*

Salinity performance curves for escape responses in guppies shape distributional patterns of closely-related species along a salinity gradient

Many locomotor traits exhibit predictable variation along environmental gradients by influencing the lower level cellular and physiological processes that determine whole organism performance. For example, thermal performance curves are commonly used to describe how locomotive performance changes with increasing temperature. Here, we examine how increasing salinity alters internal osmolality and escape performance in two closely related euryhaline fish. On the island of Trinidad, the Trinidadian guppy (*Poecilia reticulata*) is confined to freshwater whereas the swamp guppy (*Poecilia picta*), co-exists with *P. reticulata* in freshwater, but also spans into brackish and saltwater. We tested if the explanation for this distribution pattern might be rooted in the ability to maintain escape performance across a range of salinities. Because guppies are prey to larger fish, escape performance is predicted to be highly correlated with survival and fitness. We subjected both species to a physical predatory stimulus to elicit an escape response at increasing levels of salinity (0-18 psu) and measured: 1) latency of response initiation, 2) distance traveled, 3) velocity, and 4) acceleration. We found the initial transition from freshwater to brackish water (6 psu) resulted in a decline in escape performance for both species, however *P. picta* was able to more rapidly acclimate and recover performance at higher salinities. These results suggest a decline in performance following a salinity increase and the inability to rapidly acclimate in *P. reticulata* might contribute to why this species is confined to freshwater in their natural environment.

81-2 Martin, M*; Iwaniuk, AN; Logue, D; University of

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Intraspecific variation in the avian sensory system and an assessment of minimal sample size for comparative studies

The assumption that intraspecific variance is low across brain regions has led many comparative studies to rely on small sample sizes to determine volume, neuron number, and soma size. If, however, there is significant intraspecific variation in brain measurements, sampling only one or two individuals may lead to biased or incorrect conclusions. Here, we examined intraspecific variation in two sensory brain regions, nucleus magnocellularis (NM) and nucleus rotundus (nRt), among a large sample of ruffed grouse (*Bonasa umbellus*). Using unbiased stereology, we quantified volumes, neuron numbers, and soma sizes in both NM and nRt. Overall, larger brains did not have larger volumes, more neurons, or larger neurons in either brain region. Larger nRt volumes had more neurons, but this was not true of NM, and we found no significant relationships between region volume and soma size. Our data, therefore, indicate that within species, larger brain regions do not necessarily have more neurons. We then used Monte Carlo simulations to estimate confidence intervals (CI) across a range of sample sizes for NM and nRt volume, neuron number, soma size, and neuronal density. As predicted, low sample sizes had large variation around the sample mean and this variation progressively narrowed with larger sample sizes. At a sample size of n = 4-7, the bounds of the CIs began to decrease greatly and ultimately stabilized at n = 12-13 at which point the CIs closely approximated that of the sample mean. Based on these results, we advise using larger sample sizes whenever possible, and small sample sizes (< 4) should be used cautiously in comparative neuroanatomical studies.

107-11 Martin, BM*; Dudley, PN; Kashef, NS; Stafford, DM; Reeder, WJ; Tonina, D; Del Rio, AM; Foott, JS; Danner, EM; University of Amsterdam, University of California Santa Cruz, University of Idaho, University of California Davis, USFW, NOAA, Benjamin Martin; *btmarti25@gmail.com*

The biophysical basis of thermal tolerance in fish eggs

For embryos that develop within eggs, a fundamental problem posed by warming is that their demand for oxygen increases much more rapidly with temperature than their capacity for supply, which is

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constrained by diffusion across the egg surface. Thus, as temperatures rise eggs may experience oxygen limitation due to an imbalance between oxygen supply and demand. Here we formulate a mathematical model of oxygen limitation and experimentally test whether this mechanism underlies the upper thermal tolerance in large aquatic eggs. Using Chinook salmon (Oncorhynchus tshawytscha) as a model system, we show that the thermal tolerance of eggs is not fixed but instead varies systematically with features of the organism and environment. Importantly, this variation can be precisely predicted by the degree to which these features shift the balance between oxygen supply and demand. Equipped with this mechanistic understanding we predict and experimentally confirm that the thermal tolerance of these embryos in their natural habitat is substantially lower than expected from laboratory experiments performed under normoxia. More generally, we show how complex patterns of context-dependent thermal tolerance can be predicted from simple biophysical theory.

68-2 Martine, CT*; McDonnell, AJ; Bucknell University, Lewisburg, PA, Chicago Botanic Garden, Glencoe, IL; *ctm015@bucknell.edu*

"Males" that look "male" and "females" that look like "hermaphrodites": Evolution of sexual systems in Australian nightshades

While the occurrence of separate sexes among individuals is commonplace in most animals, only around 10% of the flowering plants exhibit this condition (botanically termed "dioecy"). In the economically important Nightshade Family (Solanaceae), just 1% of the species exhibit a dioecious sexual system, with nearly all occurrences happening within the "spiny solanums" of the Australian Monsoon Tropics. In these species, males present morphologically as males; but, fascinatingly, plants that appear to be bisexual in form produce non-functional pollen that renders those individuals female in function. The origins of this condition in this Australian lineage and its relationship to other cosexual systems exhibited by closely-related species have been the subject of study for decades - work that as generated multiple new species descriptions plus inferences related to seed dispersal, pollination, and population genetics. Our current work aims to illuminate the evolutionary history of the lineage using targeted

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enrichment data, evaluate areas and potential sources of phylogenetic conflict, reconstruct the evolution of diverse breeding systems, and revisit previous hypotheses regarding reproductive characters. We provide a framework of evolutionary relationships in Australian spiny Solanum, with detected discordance among gene trees highlighting a complex history that includes rapid speciation, incomplete sorting of ancestral variation, and hybridization. Outcomes related to the evolution of diverse reproductive traits suggests that sexual system transitions in this group are not only more common than previously thought, but also underlie an ongoing radiation requiring further field-based and collections-based taxonomic effort.

48-1 Martine, CT; Bucknell University; *jjsocha@vt.edu*
Welcome to the Special Session: An Introduction
An introduction to the special session in honor of Dr. Vicki Funk.

39-8 Maruf, MA*; Elhamod, M; Mandke, PK; Karpatne, A; Virginia Polytechnic Institute and State University; *marufm@vt.edu*
Biology-guided neural network for fish trait discovery
In this work, we address the problem of trait segmentation for fishes, where given an image of a fish specimen, our goal is to annotate each trait in that image with a unique color. Trait segmentation has been traditionally addressed by manual annotation on each species-image, which requires expert knowledge on trait anatomy, ontology, and phylogeny, and is slow and unscalable to a large dataset of biodiversity images that we have recently gathered from several museums. One possible solution to automate trait segmentation is to use artificial neural networks (ANN), which can detect non-linear patterns from any image. To leverage ANN, we formulate the trait segmentation problem as a semantic segmentation problem where we annotate each pixel of an input image according to the anatomical trait-class. However, a black-box ANN model learns solely from training samples and requires a lot of annotated observations. Moreover, black-box ANN ignores external biological knowledge in the training phase, which sometimes results in inconsistent outputs. To address these challenges, we develop a novel approach that incorporates biological knowledge into the

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black-box ANN model. In particular, we extract the inter-trait relationships from the fish-ontology as biological constraints and add a penalty term in the loss function of the ANN for each time a constraint gets violated. This forces the ANN model to train its parameters such that they follow the biological relationships in its prediction. Experimental results demonstrate that using biological knowledge guidance helps us to learn the ANN model from a much smaller number of annotated samples (~400 training samples for our experiments).

S9-7 Maruska, KP; Louisiana State University; *kmaruska@lsu.edu*

Modulation of acoustic communication in an African cichlid fish

Animals that cycle in and out of breeding condition often experience drastic hormonal and physiological changes that can impact context-dependent behaviors. Less is known, however, about how these reproductive-state hormone variations might influence processing of sensory information used for courtship and reproduction. Dominant males of the African cichlid fish *Astatotilapia burtoni* produce low frequency sounds as part of their visual quiver courtship displays directed at receptive females, and these females prefer to affiliate with males that produce sounds. Females cycle between gravid receptive and parental brooding stages, and auditory evoked potential recordings show that gravid females have better hearing in the frequency range of male courtship sounds compared to non-receptive brooding females. This improved sensitivity is correlated with higher circulating levels of estradiol but not androgens. Females also have greater levels of aromatase (enzyme that converts testosterone to estradiol) in the auditory midbrain as they approach spawning condition, suggesting that local estradiol production may modulate processing of salient courtship signals. Auditory-evoked single neuron responses in the torus semicircularis also suggest improved auditory sensitivity in reproductive females. We are currently testing whether acute aromatase inhibition impacts hearing sensitivity, providing a functional link to estrogenic signaling. Collectively, this work shows endocrine and reproductive-state dependent plasticity in the auditory system of female cichlids that rely on visual-acoustic courtship signals from males. For females that invest heavily in maternal care, like *A. burtoni*, improved perception of courtship-

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related sensory information as they approach spawning receptivity may allow them to make more informed mate choice decisions.

S9-1 Maruska, KP*; Butler, JM; Louisiana State University, Stanford University; *kmaruska@lsu.edu*

Introduction to the symposium sending and receiving signals: endocrine modulation of social communication

Communication in social contexts such as courtship and territoriality are crucial for reproductive success and survival in many animals. However, sending and receiving sensory information in these contexts can be profoundly influenced by an individual's reproductive and hormonal state, particularly in species that cycle in and out of breeding condition. This plasticity can also occur on different temporal scales ranging from rapid changes in seconds to longer seasonal changes over months. Unfortunately, many studies on animal communication at different biological levels do not consider potential modulatory influences that may ultimately influence how individuals produce and perceive signals that lead to appropriate behavioral decisions. This symposium brings together researchers studying different sensory systems in diverse vertebrates, coupled with focus on several classes of modulatory molecules at different levels of biological organization from molecules to whole animal behavior. Since modulatory substances in the body can influence anatomical substrates necessary for production (e.g. sensorimotor and motivational systems) and reception (peripheral sensory organs, brain) of communication signals, it is imperative to examine how these substrates are influenced with an integrative perspective to truly understand the selective pressures driving animal communication. By making researchers in diverse fields aware of this endocrine-mediated plasticity in communication across different animal taxa, various sensory channels, and distinct social contexts, we hope to inspire new research directions and interdisciplinary collaborations to advance the field.

106-5 Maruyama, S*; Weis, VM; Oregon State University, Department of Integrative Biology, Corvallis, OR; *maruyash@oregonstate.edu*

Characterizing symbiosis-specific proteins in a cnidarian-dinoflagellate symbiosis using aptamer Cell-SELEX

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Characterizing the molecular interface between the host and symbiont is critical for understanding cnidarian-dinoflagellate symbiosis. While numerous proteins involved in the regulation of symbiosis have been identified in cnidarian hosts, comparatively little is known for the dinoflagellate symbionts. Despite ample evidence that symbionts undergo a variety of molecular changes after establishing symbiosis in hosts, thus far, only a few symbiosis-specific symbiont proteins have been characterized. In this study, we developed DNA aptamers as a novel molecular tool to study symbiosis-specific proteins. DNA aptamers are single-stranded oligonucleotide probes that bind with high affinity and specificity to ligands. Aptamer development requires no *a priori* knowledge of their targets, and unlike antibodies, custom aptamer development is affordable and can be synthesized in a standard molecular laboratory. For our application, we used the model system sea anemone, Aiptasia, and its symbiont, *Breviolum minutum*, as selection targets for aptamer development. Using a procedure known as Cell-SELEX (Selective Evolution of Ligands by Exponential Enrichment), we generated aptamers that are specific to *B. minutum* in the symbiotic state, but not the free-living state. Generated aptamers can be used in live fluorescence imaging, discovery of symbiosis-specific proteins, and studying protein function. The introduction of Cell-SELEX and the DNA aptamer toolkit will allow new approaches for the study of cnidarian-dinoflagellate symbiosis, and examples of such applications will be presented.

92-1 Mason, RT*; Bentz, EJ; Oregon State University, Cornell University; *masonr@science.oregonstate.edu*

The Garden of Eden revisited: Snakes, sex, and scents - A tribute to David Crews

The Harderian gland is a large cephalic gland present in most groups of terrestrial vertebrates. Although this gland has been the focus of numerous studies for over 300 years, its physiological function has remained largely unresolved. In the red-sided garter snake *Thamnophis sirtalis parietalis*, the Harderian gland appears to be an integral component of the vomeronasal chemosensory system both by facilitating the detection of non-volatile chemical signals and as a component of the extracellular immune system. The

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Harderian gland of *T.s.parietalis* secretes its contents solely into the lumen of the vomeronasal organ and exhibits sexually dimorphic seasonal structural changes coinciding with a mutually exclusive shift in behavior from spring mating to summer feeding. Using an integrated approach employing high throughput RNA-sequencing paired with protein mass-spectrometry, we examined the functional characteristics of the Harderian gland transcriptome as well as identified and functionally characterized the proteins present in vomeronasal secretions to describe a sexually dimorphic and seasonally variable role of this tissue. The Harderian gland showed high expression of genes associated with lipid-binding proteins and others involved in the extracellular immune system. Proteins identified in the fluid of the vomeronasal organ showed an abundance of lipid-binding proteins and extracellular immune proteins. Antimicrobial properties of vomeronasal secretions were demonstrated via in-vitro bacterial killing assays. A protein of particular interest was identified as a lipid-binding protein of the lipocalin family and a likely candidate for a putative pheromone-binding protein facilitating the detection of female sexual attractiveness pheromone.

S6-4 Mathis, A; EPFL; *alexander.mathis@epfl.ch*

Deep learning tools for the analysis of movement, identity and behavior

Title: Deep Learning Tools for the Analysis of Movement, Identity & Behavior Alexander Mathis Center for Neuroprosthetics, Brain Mind Institute, School of Life Sciences École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland * alexander.mathis@epfl.ch Quantifying behavior is crucial for many applications across biology. Videography provides easy methods for the observation and recording of animal behavior in diverse settings, yet extracting particular aspects of a behavior for further analysis can be highly time consuming and computationally challenging. I will discuss the latest developments for an efficient method for markerless pose estimation based on transfer learning with deep neural networks that achieves excellent results with minimal training data (Mathis et al., Nature Neuroscience 2018). Furthermore, I will discuss how to directly predict behaviors from video as well as show new architectures for performing re-identification of animals in the

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lab and the wild. I will illustrate the versatility of these tools for multiple species across a broad collection of behaviors from egg-laying flies, via bears to 3D pose estimation on hunting cheetahs.

S2-6 Matoo, OB*; Sharbrough, J; Neiman, M; Montooth, KL; University of Nebraska-Lincoln, Lincoln, NE, New Mexico Institute of Mining and Technology, Socorro, NM, University of Iowa, Iowa City, IA; *omatoo2@unl.edu*

Phenotypic variation in energy metabolism across New Zealand snail populations

Interactions between mitochondrial and nuclear genomes impact energy metabolism in many animal taxa. Presence of discrete mitochondrial genome dictates that maintenance of mitochondrial function involves close nuclear communication. Although selection is expected to maintain functional mito-nuclear interactions, we nonetheless see high levels of genetic polymorphism for these interactions. We also lack critical understanding of how this genetic variation affects energy metabolism, especially under environmental stress. The New Zealand mud snail *Potamopyrgus antipodarum* is well suited to answer these outstanding questions. The lakes inhabited by them span wide thermal gradients, with across-lake genetic structure that enables comparisons of metabolic responses in different mito-nuclear genotypes across environmental axes. Since mitochondria are maternally inherited, coexistence of sexual and asexuals in these snails presents contrasting systems of separate vs. co-inheritance of nuclear and mitochondrial genomes. As such, this snail provides a powerful means to dissect the evolutionary and functional consequences of mito-nuclear variation on energy metabolism. Here, we integrated cellular, physiological, and metabolomics approaches to quantify variation in energy metabolism across a diverse set of wild snail lineages. Our data provide important insights into complex relationships between mito-nuclear variation, metabolic plasticity, and fitness in natural populations. We also set the stage for applying this mollusk model system to answer broader questions including: 1) How do genomes give rise to complex organismal phenotypes? and 2) How do genomic processes linked to organismal function respond to ecological and evolutionary change?

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37-6 Matsumoto, Y*; Miglietta, MP; Texas A&M University, Galveston; *yuim@tamu.edu*

Cellular reprogramming and immortality: Expression profiling reveals genes involved in Turritopsis dohrnii's life cycle reversal

When faced with environmental adversities, physical injury or senescence, medusae of *Turritopsis dohrnii* (Cnidaria, Hydrozoa) metamorphose back into the polyp stage preceded by an intermediate stage, the cyst. During its life cycle reversal, cell transdifferentiation, a mechanism in which a fully specialized cell switch into another needed cell type, occurs. To gather insight on the underlying genetic network of cell transdifferentiation and reverse development, we performed time-series and pair-wise differential gene expression analyses of the life cycle stages involved in the ontogenetic reversal of *T. dohrnii*. The time-series analyses identified genes that were enriched in the cyst during the reversal related to aging/lifespan, transposable elements, DNA repair/damage response and Ubiquitin-related processes, among others. The pairwise analyses revealed that in comparison to the colonial polyp, the medusa over-expresses genes involved in membrane transport, nervous system, mesoglea and muscle development and contraction, while genes involved in chitin metabolism, digestion, formation of the primary germ layer and cell specification processes are suppressed. Polyps formed from different developmental trajectories (asexual budding vs. reverse development) exhibited significant differences in transcriptional profile, with the reversed polyp being enriched with genes involved in processes such as chromatin remodeling/organization, matrix metalloproteinases and embryonic development, while suppressing genes involved in RAC G-protein signaling pathways. The presented genomic tools and data will further the potential of *T. dohrnii* as a research system to examine the genetic mechanisms and molecular drivers by which cells spontaneously leave a differentiated state to become a new lineage.

105-10 Matthews, DG*; Maciejewski, MF; Wong, G; Lauder, GV; Bolnick, DI; Harvard University, University of Connecticut and

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University of Illinois, Urbana-Champaign, University of Connecticut; *davematthews@g.harvard.edu*

Locomotory costs of a fibrosis based immune response in sticklebacks

Infection of a threespine stickleback (*Gasterosteus aculeatus*) by a specialist tapeworm parasite (*Schistocephalus solidus*) is known to reduce host fitness by reducing their fecundity and increasing the likelihood of predation through behavioral manipulation. Some populations of stickleback respond to tapeworm infection by developing peritoneal fibrosis, which encases the invading parasite in fibrous connective tissue. Fibrosis can reduce the growth of or even kill the parasite; however, this response may have its own set of fitness consequences. Fibrosis is known to reduce the fecundity of females and the nesting success of males, and it may have additional locomotory costs. The presence of fibrosed tissue may affect the stiffness and elastic efficiency of the body and could therefore impair locomotion. In order to examine the potential biomechanical costs of the peritoneal fibrosis immune response we induce fibrosis in sticklebacks through intraperitoneal injection of an immune adjuvant. We then use high speed videography to record C-start escape responses in fish with and without peritoneal fibrosis. We euthanized the fish and estimated the flexural stiffness of their body using a three-point bending test. Finally, we dissected the fish and visually scored them for the severity of their fibrosis response. We use the connection between fibrosis levels and body stiffness to explore variation in escape response kinematics. This is one of the first studies of the biomechanical cost of an immune response and could have implications on our understanding of the evolution of pathogen-host response in early vertebrates.

69-1 Matveev, E; Kahn, AS; Aragones Suarez, P; Guillas, KC; Yahel, G; Leys, SP*; University of Alberta, Moss Landing Marine Labs, San Jose State University, Ruppin Academic Institute; *sleys@ualberta.ca*

Sense-induced flow: Challenging Vogel's current induced flow hypothesis with in situ experiments on a deep glass sponge reef

In the 1970s, Vogel proposed a mechanism by which laminar flow over a tube could induce flow through the tube due to viscous entrainment or the Bernoulli effect. This hypothesis has been

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widely applied to both living systems and biogenic structures. Vogel first tested this hypothesis in sponges (Porifera), under the assumption that the canals were inert. A modern understanding of sponge morphology and physiology however, shows sponges possess a sophisticated sensory system, even in the canals. Glass sponges (Hexactinellida) are an ideal group with which to re-examine the hypothesis because individuals have large oscula and have a well-studied sensory system that can cause feeding current arrests. We used flow probes and oxygen sensors to test the hypothesis that *Aphrocallistes vastus* uses less oxygen (metabolic expenditure) to filter more water during higher ambient flow. We found that more water was filtered during periods of higher ambient current in only one of six individuals. However, all sponges arrested pumping independently of ambient currents, indicating control over pumping rate. We compared oxygen removal between low and high ambient flow during periods when sponges were pumping (high excurrent). Sponges removed on average 30% less oxygen when the ambient current was high. This suggests a mechanism by which the sponge senses increased ambient flow rates and reduces the cost of filtration, possibly by reducing resistance through canals. Our experiments imply that while sponges can take advantage of current-induced flow, flow through these animals is largely controlled by their complex physiology, and is thus sense-induced.

91-5 Matz, MV*; Fuller, ZL; University of Texas at Austin, Columbia University; *matz@utexas.edu*

Strong genome-wide association signal for coral's ability to host heat-tolerant symbionts

Understanding the evolution of coral heat tolerance is of prime importance for coral conservation and restoration and is an exciting challenge for evolutionary biology. In our recent genome-wide association study (GWAS) of a reef-building coral Acropora millepora we have found that the type of symbiont hosted by the coral (Cladocopium versus Durusdinium) has a larger influence on the coral's bleaching tolerance than the coral's genome sequence. Here, we revisit the same data with a different analytical methodology and demonstrate that the coral genome strongly influences the type of symbiont it is associated with. Based on a coral's genome sequence, we can predict whether it will be

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dominated by Cladocopium or Durusdinium, with the accuracy exceeding 80%. This suggests that coral adaptation to climate change may be more strongly driven by evolution of symbionts and new coral-symbiont associations relative to the evolution of heat tolerance by the coral host.

BSP-6-5 Mauro, AM*; Torres-Dowdall, J; Marshall, CA; Ghalambor, CK; Colorado State University, University of Konstanz, Norwegian University of Science and Technology; Colorado State University; *amauro@colostate.edu*

How tradeoffs constrain evolvability at the range limit of the Trinidadian guppy

Evolutionary biologists have remarked that when physical barriers and eco-physiological explanations fail to explain a specie's range limit, that range limit represents a conundrum of evolvability: why do species not continue to evolve and adapt to a broader range of habitats and expand their ranges? Here we present an evolutionary analysis of the range limit of the Trinidadian guppy (*Poecilia reticulata*) and ask: why has it been unable to adapt to the brackish waters directly beyond its current range in Trinidad despite its ability to survive in brackish water in the lab and other parts of its range? We specifically test the hypothesis that a tradeoff between salinity tolerance and competitive ability is what prevents range expansion. To test this, we conducted several experiments which allowed us to connect behavior, fitness, and gene expression to the distribution of the guppy. First, we conducted a common garden study and found a genetic basis for this tradeoff. Next, competition experiments revealed that the tradeoff is mediated by a change in social dominance. Network analysis of gene expression data of fish under different competitive and salinity conditions allowed us to uncover evidence for this tradeoff at the transcriptomic level as well. The consistent negative correlation between salinity tolerance and competitive ability across different levels of biological organization (fitness, performance, transcriptomic) provides strong evidence that this tradeoff constrains adaptive evolution in *P. reticulata* and prevents range expansion.

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108-3 May, MA*; Todgham, AE; Tomanek, L; Florida Gulf Coast University, University of California, Davis, California Polytechnic University; *mmay@fgcu.edu*

Proteomic signatures of California mussels acclimated to varying emersion temperatures and algal rations

Intertidal mussels, like the California mussel (*Mytilus californianus*), routinely experience fluctuations in their natural environment, including temperature, aerial exposure, and food availability. The intertidal zone is inherently stressful, thus successful colonization of this habitat necessitates high phenotypic plasticity to multiple stressors. Recent research has shown that previous food ration and thermal history significantly influence the survival and physiology of these mussels during extreme heat events, yet the molecular mechanisms that contribute to increase thermal resilience are not well understood. As part of a broader study, we used a shotgun proteomics approach (LC-MS/MS) to investigate molecular-level variation in gill tissue of *M. californianus* acclimated to combinations of high or low algal rations and high or low emersion temperatures in environmental chambers that mimic tidal cycles. To account for natural rhythms, samples were collected every 3 h for 48 h, following the 3 wk acclimation period. We employed label-free quantification methods to assess significant changes in protein abundance among the acclimation groups. Overall, we were able to identify 350 proteins and quantify 175 proteins within the 320 samples analyzed. Preliminary analyses of our initial time points indicate that acclimation temperature may have more of an effect on protein abundance than algal ration, including significant changes in small heat shock protein 24 and ATP synthase. We expect to see interesting patterns emerge in protein abundance over time that correspond to the low tide cycles (i.e., emersion temperatures), feeding events, and recovery from aerial exposure.

104-1 Mayerl, CJ*; Steer, KE; Chava, AM; Bond, LE; Edmonds, CE; Gould, FDH; Stricklen, BM; Hieronymous, TL; Vinyard, CJ; German, RZ; NEOMED, Rootstown, OH, Rowan School of Osteopathic Medicine, Stratford, NJ; *cmayerl@neomed.edu*

Hyoid movements are correlated with contractile patterns of the hyoid musculature during infant feeding

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All mammalian infants suckle. This process requires the coordination of over 25 paired muscles to coordinate the movements of oropharyngeal structures, including the hyoid. The hyoid is suspended in a muscular and ligamentous sling, and its movements play a role in ensuring a safe swallow. Although we understand the general activation patterns of these muscles during infant feeding, our expectations of how they function to direct movements of the hyoid are primarily based on anatomical inferences. Here, we used biplanary videofluorscopy of infant pig feeding to track movements of the hyoid bone synchronized with contractile patterns and EMG activity of geniohyoid, stylohyoid, thyrohyoid and omohyoid, four muscles attached to the hyoid that are active during swallowing. We also animated diceCT-scanned muscles together with hyoid movements to estimate how muscle orientations relative to the hyoid changed during a swallow. Muscle contractile patterns were highly correlated with hyoid movements, and different muscles exhibited different contractile patterns. For example, stylohyoid was concentric during hyoid elevation, whereas at the same time, omohyoid exhibited eccentric activity. We also found that the line of action of the muscles changed following hyoid elevation, with dorsoventral angles being oriented more ventrally at peak hyoid elevation. Our results demonstrate that muscle contractile patterns are varied, and that the line of action of a muscle changes throughout a swallow. Finally, with just four muscles, we have illustrated the complexity of achieving hyoid movement during swallowing, justifying the need for further in vivo research.

31-9 Mazzarella, KT*; Bernhard, MC; Mote Marine Laboratory, Sarasota, FL, Mote Marine Laboratory, Sarasota, FL ; *kristen@mote.org*

To cage or not to cage? Effectiveness of caging sea turtle nests on Gulf of Mexico beaches

Sea turtle nest depredation has been identified as one of the primary threats to the recovery of loggerhead sea turtles (*Caretta caretta*) in the Northwest Atlantic Population. In order for a strong recovery to occur, it is recommended that depredation be less than ten percent on a beach. Self-releasing cages and screens have traditionally been utilized to prevent predator intrusion into sea turtle nests. Studies have shown that initial nest depredation

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increases the likelihood of future depredation on the same nest; therefore self-releasing cages may be used to protect the remainder of the clutch. However, caging is costly both in time and resources, and may have unforeseen impacts on the ecosystem. We analyzed 731 nests at four field sites to determine whether the use of caging after initial depredation (as a predator deterrent) was beneficial to nest survival. In addition, we looked at trends in depredation when caging was not employed. We compared caged and not caged areas across and within years on three barrier islands on the Gulf of Mexico in Sarasota County, Florida, USA. Predators such as raccoons, armadillos, and coyotes are known causes of nest depredations in this region. Preliminary results indicate that for most areas when cages were employed, the depredation rate was higher and/or overall emergence success was lower. Based on these findings, the use of cages after initial depredation, while protecting the remainder of a single nest, may not benefit the overall reproductive output for the population.

97-6 McCarter, MG*; Loudon, C; University of California, Irvine; *marlom@uci.edu*

Rapid recoil of filiform insect antennae

Many insect antennae, including those of house crickets (*Acheta domesticus*), are filiform. These mechanosensory structures are used for tactile sensing in addition to other sensing functions; as such they readily bend in response to physical contact with objects in their environment. We analyzed the recovery of antennae passively deflecting around a fixed obstacle at four distances along the flagellum. Measurements were made on live restrained crickets, with the joints associated with the first two segments (the scape and the pedicel) held rigid with epoxy to ensure the deflections were passive (there are no muscles in the flagellum). The antennae returned quickly to their initial positions after being perturbed in either ventral or dorsal directions. After 0.1 seconds an antenna was within 30% return of its original position (2.8 mm from its original position after an average deflection of 9.6 mm, n = 156). There was no significant difference in return speed between ventral and dorsal perturbations. The maximum speed of an antenna was dependent on the distance of the obstacle along the flagellum, with the speeds differing with sex of the cricket for some

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distances. An antenna's quick recoil allows for it to quickly reposition for new tactile input.

47-6 McCulloch, KJ*; Neal, S; Napoli, F; Daly, C; Coleman, J; Koenig, KM; Harvard University; *kmcculloch@g.harvard.edu*
Gene duplication and co-option in the evolution and development of the squid eye
The cephalopod visual system is a stunning example of convergence in a complex trait. However, little is known about the genetic and molecular basis of cephalopod eye development. A major contributor to the evolution of biological novelty is thought to be the duplication of genomic DNA. We sought to investigate if this might contribute to cephalopod-specific visual system novelties. Members of the Krüppel-like factor/specificity protein (KLF/SP) sub-family of C2H2 zinc-finger transcription factors were found to be highly expressed in the visual system transcriptome of the squid *Doryteuthis pealeii*. With few exceptions, the evolution and function of this gene family has not been studied in Spiralia. A thorough phylogenetic analysis found multiple duplications and losses of the *SP6-9* gene throughout spiralian lineages and at least one cephalopod-specific duplication. We show in particular that *D. pealeii* expresses two recent duplicates of *SP6-9* (*a* and *b*) in overlapping neural and limb domains but one paralog showed unique expression in the developing squid lens, suggesting a neofunctionalization of DpSP6-9a. We sought to further investigate the role of SP6-9a in the developing squid lens and found that *DpSP6-9a* is expressed in the lens in conjunction with a regulatory cassette typically found in proximal-distal patterning of animal appendages. This work supports the hypothesis that gene duplication and co-option contribute to the appearance of novel traits like the cephalopod image-forming eye and to the morphological diversity found within Spiralia.

BSP-8-7 McDonald, MS*; Cohen, JH; Porter, ML; University of Hawai'i at Mānoa, University of Delaware; *marisam7@hawaii.edu*
Visual physiology of larval stomatopod crustaceans
Stomatopod crustaceans are known for having one of the most complex visual systems in the animal kingdom. While the adults have

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historically received the majority of attention, limited work has been focused on larval stomatopods. Stomatopod larvae must survive as planktonic organisms for days to months before settling. One key aspect of survival is the visual system, which is used for a wide range of important biological tasks. It has been generally understood that pelagic crustacean larvae with compound eyes have a single spectral class of photoreceptors. However, recent evidence suggests that stomatopod larvae may have multiple photoreceptor types, including ultraviolet. Based on this, the visual physiology of stomatopod larvae was examined using electroretinogram (ERG) recordings and behavioral phototaxis responses. Larval stomatopods were collected in Summer and Fall 2020 on Oahu, Hawaii. ERG recordings were completed using broadband comparisons at matched irradiances of UV (peak 330), blue (peak 500), green (peak 530), and orange (peak 570) filtered light across multiple species and larval stages. Additionally, matched phototaxis trials were completed at the same irradiance levels and colors to determine if the physiological response translated to behavior. This work expands upon recent research into the complexities of larval stomatopod visual systems, once believed to be simple and uniform. Larval stomatopods are the first larval crustaceans to show evidence of UV vision, and this work is important to increase our understanding of the visual ecology of the early life stages of these unique crustaceans.

48-3 McDonnell, A*; Moore, M; Sakai, AK; Weller, SG; Wickett, N; Chicago Botanic Garden, Oberlin College, University of California, Irvine, University of California,
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New perspectives on the evolution of plant breeding systems in the radiation of Hawaiian Schiedea (Caryophyllaceae)

The evolution of island lineages provides outstanding opportunities to understand evolutionary processes affecting the diversification of species, plant reproductive systems, and pollination systems. Using *Schiedea* (Caryophyllaceae), the fifth-largest plant radiation in the Hawaiian Islands, we have investigated genetic and ecological factors promoting separate sexes or autogamy and changes in pollination systems as species radiated into a variety of habitats. Hybridization and gene flow may also promote evolution of

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separate sexes through introgression of male sterility genes from gynodioecious or dioecious species into hermaphroditic species. Ongoing studies using genomic approaches may help to resolve not only the phylogeny of Schiedea but also the number and relative timing of independent transitions to dioecy, the inference of which may be impacted by historical introgression, incomplete lineage sorting, and genome duplication throughout the radiation of the genus. Complete genome sequences for three species will be used to support the inference of these processes, particularly the history of whole genome duplication. Initial estimates of gene diversity relative to species diversity will be based on these genome data as well as transcriptome data for twelve species. While preliminary, this work will also contribute to the ongoing conservation of *Schiedea* in Hawaii.

38-6 McElroy, EJ*; Faust, S; College of Charleston; *mcelroye@cofc.edu*

Ecomorphology of pelvis shape in lizards

The pelvis forms a key anatomical and functional linkage between the axial and appendicular skeleton. It is composed of three main bones and is an anatomically complex structure. Yet, for many groups of limbed animals, we have limited knowledge of the standing variation and the ecological, phylogenetic and functional correlates of pelvis shape. This study quantifies pelvis shape in a sample of lizards spanning ecological and phylogenetic diversity. Geometric morphometrics was used to describe the morphospace occupied by the lizard pelvis. Pelvis shape was mapped onto lizard phylogeny to explore the evolutionary history of shape and the effects of habitat use and locomotor mode were tested in a phylogenetic context. Results suggest that clades of lizards have distinct pelvis shapes and that both habitat use and bipedalism are correlated with distinct pelvis shapes.

77-10 McElroy, KE*; Serb, JM; Iowa State University; *kmcelroy@iastate.edu*

Evolution of molluscan opsin repertoire

Evolutionary changes in molluscan opsin repertoire McElroy KE, Serb JM kmcelroy@iastate.edu Iowa State University, Department of

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Ecology, Evolution and Organismal Biology, Iowa, USA Eyes have evolved numerous times and molluscs have the most varied eye types of any animal phylum. We know very little about how these different molluscan eye types evolved, including the sets of genes recruited to support their development and function. Opsins are the protein component of the photopigment that triggers the visual transduction pathway and fundamental to the genetic architecture of vision. Broadly, we know that mollusks have three groups of opsin families: r-opsins, xenopsins, and tetraopsins, which include neuropsin, Go-opsin, and retinochrome. However, the variation in opsin composition has not been characterized in mollusks due to the previous paucity of assembled molluscan genomes. Now that mollusc genomes are increasingly available in public datasets, we can begin comprehensive phylogenomic comparisons within this diverse phylum. We collected opsin sequences from dozens of molluscan genomes to characterize their opsin repertoires and analyze the history of opsin family evolution across the phylum. We found extensive opsin family expansion and contraction, particularly within r-opsins and xenopsins in a lineage-specific manner; tetraopsin diversification is much rarer in molluscs. The fluctuations in opsin repertoire appear to be limited to bivalve and gastropod lineages, with cephalopods maintaining relatively few opsins and having lost at least two major opsin groups: neuropsins and Go opsins. These results help set the stage for connecting genomic changes, including opsin family expansion and contraction, to patterns of evolution in eye type and vision in molluscs.

72-12 McGechie, F*; Grider-Potter, N; Nalley, TK; Fricano, E; Middleton, KM; Holliday, CM; Ward, CV; University of Missouri, Rocky Vista University, Western University of Health Sciences, Western University of Health Sciences; *frm7w6@mail.missouri.edu*
Primate nuchal anatomy and function
Within primates, the nuchal region is considered particularly important for understanding variation in postural and locomotor behaviors. Nonetheless, there has not yet been a quantitative study of comparative nuchal muscle function. We investigated the influence of 1) trunk posture, 2) head turning behaviors, and 3) forelimb-dominated below-branch suspensory behaviors on the nuchal musculature in five primate species with a diversity of positional

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behavioral specializations. We used DiceCT, 3D muscle fascicle-tracking, and 3D muscle visualization to compare the attachment sites, 3D orientations, and force generating capacity of 19 muscles. Results demonstrate that all muscle force estimates scale with isometry. Suspensory taxa have a more dorsoventrally oriented cranial belly of the trapezius muscle when compared to non-suspensory species. Orthograde primates have relatively less powerful longissimus capitis muscles than do pronograde primates. Primates that employ dramatic head-turning during locomotion have more transversely oriented (*Carlito*) and more powerful sternocleidomastoid as well as more powerful obliquus capitis superior muscles (*Carlito* and *Propithecus*). These results support the hypothesis that positional behaviors influence the moment-generating capacities of certain key nuchal muscles. Osteological correlates of nuchal muscles may be useful in reconstructing fossil primate behaviors, but more investigation is necessary especially into the effects of phylogeny.

S3-7 McHenry, MJ*; Peterson, AN; Soto, AP; University of California, Irvine; *mmchenry@uci.edu*

Chance events and strategic behavior in the predator-prey interactions of fishes

Predator-prey interactions are critical to the biology of a diversity of animals. Understanding predatory behavior can offer critical insight into the ecology and evolution of a species and a means to evaluate the biological significance of sensing and locomotion. In this pursuit, models of mechanics and behavioral algorithms offer a basis for understanding the major factors that govern the motion of a predator or prey. However, the deterministic framework of mathematical modeling commonly neglects the significance of natural variation in performance and the role of chance events. Descriptive statistics may conversely characterize patterns of variation without offering a predictive understanding. Here we present a research program that aims to test the effects of biological variation in sensing and locomotion on prey capture through an application of agent-based stochastic modeling that is common to some fields of economics. Over a series of studies, we performed kinematic measurements of predator-prey interactions in fishes and modeled the behavioral algorithms of both animals with

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both fixed and random parameters. We interrogated the effects of variation in the sensory and motor characteristics of these animals through sensitivity analyses using a Monte-Carlo approach. This work has shown how predatory fishes target their prey, tested the relative importance of sensory and locomotor performance in prey survival, and examined how prey strategy varies with the sensory cues offered by a predator. Our findings illustrate the utility of agent-based stochastic models for testing the sensorimotor basis of prey capture and predator evasion. This approach has the potential to offer insight into the mechanistic basis of a wide variety of behaviors.

25-8 McInnis, SJL*; Franz-Odendaal, TA; Saint Mary's University, Halifax, NS, Mount Saint Vincent University, Halifax, NS; *shea.mcinnis@smu.ca*

Characterizing the effects of increased muscle load on the flat scleral ossicles of Danio rerio

The musculoskeletal system is responsible for executing movements, and is comprised of the muscles and the skeleton of vertebrates. The close association between these two organ systems begins early in the development, as muscles insert into, and begin to exert mechanical forces known as muscle load on the immature skeleton. Muscle-based mechanical forces impact both the early development and the maintenance of the skeleton, and sensing these forces largely involves the non-dividing bone cells (osteocytes). Other skeletal cells such as the bone depositing osteoblasts, and the bone resorbing osteoclasts are also known to respond to mechanical stimuli. in teleosts Many studies have investigated the role of muscle load on the skeleton, but very few have investigated the role of muscle load on flat bones. The aim of this study was to understand the role played by muscle load in the development and maintenance of endochondrally ossifying flat bones called scleral ossicles in the zebrafish, *Danio rerio*. Following a period of increased muscle load, the morphology of the scleral ossicles was examined, along with the activity of osteoclasts and osteoblasts. Overall it was found that while the morphology of the ossicles were not significantly affected, the activity of osteoclasts and osteoblasts significantly changed. These findings help to understand the effects of muscle load on the development and

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maintenance of the skeleton on a fundamental level, and may have implications in mitigation strategies of metabolic bone disorders.

73-10 McInroe, BW*; Baryshnikov, YM; Koditschek, DE; Full, RJ; Univ. of California, Berkeley, Univ. of Illinois, Urbana-Champaign, Univ. of Pennsylvania; *bmcinroe@berkeley.edu*

Discovering simple mechanical models from motion data: A novel representation shown in ground righting geckos

Locomotor behaviors result from high dimensional, nonlinear, and dynamically coupled interactions between an organism and its environment. The templates and anchors hypothesis resolves this complexity by anchoring simple mechanical models in physiologically realistic morphologies. By collapsing high-dimensional biological measurements to the simplest representative models, templates have led to insight on neuromechanical control, and enabled the development of bioinspired robots. However, due to the lack of a general methodology for identifying templates from behavioral data, the use of templates to study animal and robot motion has largely been limited to a few well-studied behaviors. Further, reliance upon existing analytic models limits the ability to discover new mechanisms in rich datasets. The promise of big animal mobility datasets from new motion capture labeling methods motivates the aim for a general, data-driven paradigm to identify templates in motion data. We present the vielbein template representation (VTR), a new approach for modeling template-anchor pairs that enables the construction of local model coordinates directly from multidimensional kinematics datasets. We present preliminary results from applying our approach to 3D, whole body ground righting kinematics data collected with *Hemidactylus* geckos, leading to testable neuromechanical control hypotheses. We conjecture that the VTR approach is a tractable methodology for relating animal and robot data, and will enable new insight into how multifunctional appendages anchor rich behavioral repertoires, and how common physical principles underlie similar maneuvers in morphologically diverse organisms.

82-9 McKinney, JE*; Ludington, S; O'Connell, LA; Stanford

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University, Department of Biology; *jmckinn@stanford.edu*

Neural regulation of tadpole aggression

Aggression in juveniles is an evolutionarily adaptive behavior documented in many species, but the neural mechanisms behind these displays are poorly understood. In the Mimetic poison frog (*Ranitomeya imitator*), tadpoles live in small pools with limited resources and have evolved aggressive tendencies towards conspecific tadpoles in defense of these resources. Tadpoles will attack, kill, and cannibalize other tadpoles as a primary resource defense mechanism. We examined the neural basis of neonate aggression in these tadpoles by comparing individuals that were placed in aggressive encounters and individuals placed in an environment with a non-threatening stimulus. We first did a longitudinal study to determine that the tadpoles were most aggressive when they were around five or six weeks old. We then compared patterns of generalized neural activity using immunohistochemical detection of phosphorylated ribosomes and a candidate neuropeptide, arginine vasotocin, which has been implicated in aggression in other vertebrates. Vasotocin cells in the preoptic area of the hypothalamus were not more active during aggression. We then examined neural activation across several brain regions suspected to be involved in aggression: the amygdala, hypothalamus, and medial pallium. During aggression, this showed us that the medial pallium had the most neural activation compared to controls and the other brain regions. To determine what cell types influence aggression, we then used phosphoTRAP to molecularly profile active neurons in tadpoles showing aggression compared to controls. Current work is focusing on identifying distinct neuropeptides and doing brain specific knock-down to determine individual neuropeptide influence on aggressive behavior. Overall, this project is advancing our understanding of how aggression is regulated in the juvenile brain.

30-3 McMahon, EK*; Youatt, E; Cavigelli, S; Pennsylvania State University; *ekm5112@psu.edu*

Associations between multiple physiological mechanisms within an individual

Physiological responses of multiple systems (e.g. endocrine, immune, autonomic) are key for determining how animals respond to

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their environment. Understanding how multiple physiological mechanisms function together provides further insight into how individuals function. The objective of this study was to determine if there are reliable relationships among different physiological systems within an individual. We measured several physiological responses within the same individuals and used correlational analysis to identify related processes. We measured hormonal stress response, innate and adaptive immune function, and sympathetic reactivity in 54 adult male Sprague-Dawley rats. To measure hormonal stress responses, we conducted an acute restraint test and measured glucocorticoid (GC) responses. Innate immunity and basal GCs were measured during an 8-hour period after lipopolysaccharide injection. Adaptive immunity was measured with relative hind foot swelling after keyhole limpet hemocyanin (KLH) re-exposure. And heart rate was measured non-invasively during an acute restraint stress to determine fluctuations in sympathetic activity. We found that GCs were associated with most other physiological measures; specifically, elevated GCs during the innate immune challenge were associated with elevated pro-inflammatory cytokine responses (TNF-alpha and IL-6). Additionally, elevated cell-mediated immune responses were associated with elevated circulating GCs during KLH exposure and elevated circulating TNF-alpha levels during the innate immune challenge. Heart rate in response to restraint was not associated with any physiological measures. These results are the first step in understanding how different physiological systems interact to support organismal responses to complex environmental challenges.

60-1 McNamara, MP*; Cadney, MD; Castro, AA; Hillis, DA; Kallini, KM; Macbeth, JC; Schmill, MP; Schwartz, NL; Hsiao, A; Garland, T; Univ of California, Riverside, UCR; *mloui007@ucr.edu*

Reduction of the adult gut microbiome decreases wheel-running behavior in mice selectively bred for high voluntary wheel running

Coevolution of the gut microbiome with the host has resulted in the microbiome influencing host physiology and even behavior. Previous research shows the gut microbiome can affect exercise ability, but possible effects on physical activity are unknown. Here, we show that elimination of the gut microbiome via antibiotic treatment can reduce voluntary exercise in mice, but only in lines that have been

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selectively bred for high voluntary wheel running. We studied females from a unique artificial selection experiment in which 4 replicate High Runner (HR) lines are bred for voluntary wheel running and compared with 4 non-selected control (C) lines. HR differ from C in several traits that likely interact with the gut microbiome, including ~3 fold higher daily running distance, higher body temperatures when running, higher spontaneous physical activity when housed without wheels, and higher food consumption. After two weeks of wheel access to reach a stable plateau in daily running, mice were administered broad-spectrum antibiotics in their water for 10 days. Antibiotic treatment caused a significant reduction in wheel running in the HR mice (-21%) but not in the C mice. Antibiotic treatment did not reduce food consumption or body mass in either HR or C mice, suggesting that neither linetype became sick. These results indicate that gut microbes play a role in voluntary exercise and provide evidence for the coevolution of the HR mice with their gut microbiome. NSF DEB-1655362 to TG and R35GM124724 to AH.

35-1 McShaffrey, C*; Forbes, E; Long, JH; Vassar College; *jolong@vassar.edu*

Behavior of the encapsulated embryos of little skates, Leucoraja erinacea

The embryo of the little skate, *Leucoraja erinacea*, faces the daunting task of living for up to a year isolated in its egg capsule at the bottom of the ocean. After a few months, jelly blocking each tendril degrades, opening the slits that permit water flux. As gas exchange becomes a physiological imperative, embryos must actively ventilate their capsule. As they do so over months, their growth changes their morphology, sensory capacity, and, as a result, their physical interactions with the capsule. Thus we expected the embryo's behaviors to change dramatically over the course of their egg-bound development. Previous research has shown that embryos ventilate their capsule by undulating their tail to pump water through the slits in the tendrils. However, this picture does not capture the full scope of their behavioral complexity throughout development. In this exploratory study, we observed and videotaped embryos in their capsules during three late developmental stages. Embryos changed their movement patterns, how

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they interacted with their capsule as they grew, how they responded to vibrations, and, surprisingly, how they responded to the voice of the investigator. After cataloging behaviors, we analyzed their interactions as a network of finite states, including threshold triggers and changes over developmental time. Building from preliminary qualitative work, we find clear evidence that the embryos of little skates are doing much more, behaviorally, than just ventilating their egg capsule.

101-9 Medina-Baez, OA*; Aponte-Gutiérrez, AF; Veselka, AJ; Watling, JI; John Carroll University, Cleveland, Ohio, Universidad Nacional de Colombia, Bogotá; *oam23@case.edu*

Are populations of the salamander Bolitoglossa altamazonica declining at low elevations due to rising temperatures?

Amphibians are the most extinction-prone clade of terrestrial vertebrates. Amphibians have declined not only in areas affected by deforestation, but also in seemingly pristine forests with low human impact. These ‘enigmatic’ declines are often associated with the chytrid fungus, but other studies suggest that climate might play an important role in some declines. Ectotherms in the tropics are at special risk of decline because of their narrow warming tolerances (WTs), the difference between an organism's body temperature and its tolerance to high temperatures (the critical thermal maximum, or CT_{max}). In this study, we measured population densities and WT in four populations of a tropical lungless salamander, *Bolitoglossa altamazonica*, at elevations ranging from 500 - 1150 m in the eastern Andes of Colombia. We found a significant, positive relationship between WT and population abundance: population densities increased with WT, which in turn increased with elevation. We report an alarming decline at one lower elevation site, where salamander counts have declined by 70% in the past ten years. As the thermal landscape in the tropics continue to change, understanding species' response to warming will be crucial for habitat conservation practices.

S5-10 Mekdara, PJ*; Schwalbe, MAB; Tytell, ED; National Institute of Health, Lake Forest University, Tufts University; *prasongmekdara@gmail.com*

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Tail beat synchronization of schooling giant danios is altered after lateral line ablation and regeneration

It has long been hypothesized that swimming in schools allows fish to save energy. To save energy, fish must extract energy from the wakes of their neighbors, a feat that requires them to stay in certain positions relative to their neighbors and synchronize their tail movements to their neighbors. However, how fish synchronize their swimming movements is still not well understood. Fish can use their flow sensing lateral line system to maintain position in a school. The lateral line system is divided into two branches. The anterior branch, located on the head, encounters largely undisturbed free-stream flow, while the posterior branch, located on the trunk and tail, encounters flow that has been affected strongly by the tail movement. Thus, we hypothesize that the anterior branch may be more important for regulating position within the school, while the posterior branch may be more important for synchronizing tail movements. Our study examines functional differences in the anterior and posterior lateral line in the structure and tail synchronization of fish schools. For one fish in the school, we ablated only the anterior lateral line, only the posterior portion, or all of the lateral line by protecting either the head or the trunk with low melting point agarose during hair cell ablation treatments. Ablating any portion of the lateral line system causes fish to swim in a "box" or parallel swimming formation, different from the control diamond pattern. Ablating only the anterior lateral line did not substantially reduce tail beat synchronization but ablating only the posterior lateral line caused fish to stop synchronizing their tail beats, largely because the tail beat frequency increased dramatically. Most importantly, the posterior lateral line system played a major role in determining tail beat synchrony in schooling fish.

80-2 Mendoza, E*; Azizi, E; University of California, Irvine; *emendoz7@uci.edu*

Muscles modified for elastic energy storage enhance jump performance in frogs

Jumping requires substantial mechanical power. Some frog species can exert high jumping power outputs through the use of elastic recoil mechanisms. Across anuran species, jumping power varies

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substantially despite relatively similar isolated muscle power outputs. This variability suggests interspecific differences in elastic energy storage, yet this remains untested. In this study, we measured differences in elastic energy storage (i.e., work) between Cuban tree frogs, cane toads, and bullfrogs. We used an isolated muscle preparation of the *plantaris longus* muscle-tendon unit (MTU) to characterize the force-length property of this muscle. Then, we quantified the maximal amount of energy stored in elastic structures of this MTU for each species. We found that mass-specific work differed across species. In particular, we found that the Cuban tree frog's MTU stored approximately two and a half times more mass-specific energy than cane toad's MTU and one and a half times more than the bullfrog's MTU. Additionally, we found that mass-specific force was approximately two times greater in Cuban tree frogs. Moreover, we found that the *plantaris longus* in Cuban tree frogs had higher pennation angles than the other species suggesting that muscle architecture was modified to increase force capacity through packing of more muscle fibers. Finally, we found that the elastic elements in the *plantaris longus* MTU were stiffer in Cuban tree frogs. Our results suggest that muscles interacting with elastic structures may be tuned to generate higher forces, operate against stiffer elastic elements in order to augment elastic energy storage.

82-7 Menelaou, E*; Katz, HR; Hale, ME; University of Chicago, Chicago, IL, Marine Biological Laboratory, Woods Hole, MA; *emenelaou@uchicago.edu*

Axial touch sensation and its effects on motor output and swimming behavior in larval zebrafish

During locomotion animals continuously adjust their movements to navigate complex and cluttered environments. Such adjustments are made possible through sensory feedback. One key modality providing feedback on movement is mechanosensation. In fishes there are vast arrays of mechanosensors on the surface of the body. These sensors allow fish to sense contact and movement of body elements. Here we examine one type of these surface mechanosensors, the Rohon-Beard (RB) neurons, which are spinal neurons of fish and aquatic amphibians and are the predominant surface mechanosensors in larval stages of development. In larval zebrafish, RBs are distributed

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along the length of the spinal cord and have elaborate arborizations into the skin. Here, we describe the anatomy of RBs in zebrafish larvae and investigate their function. We show that RBs are rapidly adapting cells that can signal the onset and offset of mechanical stimulation and can use rate and temporal coding mechanisms to encode stimulus intensity. At rest, the intensity of the mechanical stimulation influences the reliability and the latency of the swim response. During ongoing swimming bouts, data suggest that the location, amplitude and timing of the mechanical stimulation lead to differences in the modulation of motor output. We find that a high intensity stimulus during swimming activity can interrupt and reset the rhythm of cyclic activity but a lower intensity stimulus at the same location has no effect on the periodicity of cyclic bursting. By understanding the mechanosensory mechanisms of modulation we can gain insight into how fish and other organisms generate the adaptive movements that allow them to perform well in structure-rich and changeable environments.

BSP-3-7 Mentesana, L*; Andersson, MN; Casagrande, S; Goymann, W; Isaksson, C; Hau, M; Max Planck Institute for Ornithology, Lund University; *lmentesana@orn.mpg.de*

Yolk fatty acids, but not androgens, predict offspring fitness in wild birds

Maternal effects can increase offspring phenotypic variation. In birds, mothers can influence the developmental environment of chicks by secreting various substances into the egg yolk. Recent studies have demonstrated that yolk substances can interactively affect offspring phenotype, but the implications of such effects for chick fitness and phenotype in natural populations have remained unclear. We measured 31 yolk components including steroid hormones, antioxidants and fatty acids in wild great tit eggs (*Parus major*) during two breeding seasons. We tested for associations among yolk substances, and for relationships between component groupings and offspring fitness and phenotype. Hatching and fledging success were explained by yolk fatty acids (including saturated, mono- and polyunsaturated fatty acids) - but not by androgen hormones and carotenoids. Fatty acids also accounted for more variation in nestling oxidative status and size than androgens and carotenoids. Our results indicate that fatty acids are

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important yolk substances that shape offspring fitness and phenotype in wild populations. Therefore, future work on maternal effects needs to incorporate the multivariate composition of the egg and avoid focusing on single yolk components. Since several fatty acids are of dietary origin, our study also highlights a possible role of the environment in shaping maternal effects and consequences for offspring.

10-5 Merces, GOT*; Pickering, M; University College Dublin, Ireland; *george.merces@ucdconnect.ie*

Visualisation and ionic control of adhesive release in prey capture of the ctenophore Pleurobrachia pileus

Tentaculate ctenophores, such as *Pleurobrachia pileus*, utilise a strong, fast-acting adhesive for prey capture. The adhesive is stored safely along their two branched tentacles in specialised cells called colloblasts. When prey contacts a tentacle, the adhesive is released and binds the prey. This mechanism of release and other basic questions about the adhesive are yet to be answered. To better understand the mechanisms controlling adhesive release, live video microscopy was applied to visualise adhesive release in response to probing. Probes of various surface chemistries were compressed into tentacle fragments and slowly withdrawn to see individual adhesion events. We found that compression was a requirement to stimulate consistent adhesive release, and that the larger the area compressed the more colloblast cells released adhesive. However, the proportion of colloblasts releasing adhesive was low. This finding suggests colloblast discharge may be a stochastic event, with a low baseline probability of activation. However, the exact mechanism underpinning colloblast discharge is unknown. To better understand the intracellular mechanisms governing adhesive release, exogenous perfusion of tentacle fragments with artificial sea water (ASW) was visualised under video microscopy. ASW of the same tonicity but containing higher proportions of calcium or potassium resulted in the formation of large vesicles along the surface of the tentacles, indicating adhesive release. High levels of magnesium or sodium resulted in relaxation of the tentacles, with no formation of these vesicles. These results indicate ionic regulation of adhesive release from colloblasts, and combined with other studies of

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colloblast origin, add weight to a potential neuronal origin of colloblast cells.

S4-18 Merrill, AN*; Hirzel, GE; Westerman, E; University of Arkansas, Fayetteville; *abbynichole19@gmail.com*

Using citizen science to assess the effect of wing pattern and weather on butterfly behavior

Signaling in insects is used as communication and for attraction of mates. Brighter colors can produce stronger signals when attracting potential mates. However, more vibrant colors can unintentionally attract negative attention from predators. Environmental conditions such as weather can play a role in visual signaling as well, by influencing the wavelengths of light available, and subsequent signal detection. We do not know, however, whether signals butterflies present broadly correlate with how they behave. In this study, we looked at the wing patterns and behavior of butterflies in Northwest Arkansas over a 3.5-year period to assess the relationship between wing pattern, weather, and behavior. We used observational data collected by hundreds of University of Arkansas students and Northwest Arkansas citizens through surveys at both the Botanical Garden of the Ozarks and the general Northwest Arkansas region. We found that weather and wing color influenced general butterfly behavior. Butterflies fed more often on cloudy days than sunny days. Black and brown butterflies fed more often, while yellow and white butterflies flew more often relative to other butterfly colors. We also found that there was an interaction between the effects of weather and wing color on butterfly behavior. White and yellow butterflies fed more and flew less on cloudy days than sunny days, relative to the other colors of butterflies. Furthermore, butterfly color influenced the choice of flower colors butterflies fed on. More brown butterflies landed on yellow flowers relative to other colors of butterflies. These results suggest that flower choice may be associated with butterfly wing pattern, and that different environmental conditions may influence butterfly behavior in wing-pattern-specific ways.

21-1 Messerly, KI*; Coomes , CM; Derryberry, EP; University of Tennessee - Knoxville; *kmesserl@vols.utk.edu*

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It's getting hot in here: The effects of temperature on behavioral allocation in songbirds

Climate change affects habitats across the world through warming temperatures, and animals are altering their behaviors in response. Individuals are re-allocating time and energy investments away from behaviors such as foraging and mating toward thermoregulatory behaviors. Reducing investments in mating behaviors could reduce the likelihood of mating, potentially decreasing reproductive success. Songbirds are sensitive to heat variation and have well studied thermal physiology. We exposed male zebra finches to three temperature treatments: below (27° C), within (35° C), and above (43° C) the thermal neutral zone while viewing a female. We then quantified thermoregulatory and courtship behaviors. We hypothesize that zebra finches will vary in how they allocate their time to such behaviors in different treatments due to varying thermoregulatory needs. Zebra finches in treatment groups above and below the thermoneutral zone spent more time engaged in thermoregulatory behaviors than the thermoneutral treatment group. Birds in the thermoneutral zone will spend more time invested in mating behaviors, than treatment groups above and below the thermoneutral zone. By understanding the effects of heat stress on captive zebra finches we are better able to make inferences on immediate regulation responses to temperature threats and identify trends between captive and wild populations.

49-7 Metz, HC*; Miller, AK; You, J; Kriete, A; McBride, CS; Princeton University; *hmetz@princeton.edu*

Evolution of a mosquito's hatching behavior to match its human-provided habitat

A subspecies of the mosquito *Aedes aegypti* recently evolved to specialize on human hosts—preferring human odor over non-human animal odor and living alongside humans rather than in forests like its ancestors. Here, we report on how this anthropophilic specialist has evolved to thrive in habitats near humans. We find that derived domestic (*Ae. aegypti aegytpi*) mosquito larvae hatch readily in oxygen-rich water, while ancestral *Ae. aegypti formosus* require deoxygenated water. Using genetic crosses, we demonstrate this behavioral difference is heritable, and decompose the genetic basis into a maternal effect that persists across

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conditions, as well as a zygotic effect present only in oxygen-rich water (i.e., GxE). Our findings—revealing an interaction between genotype and oxygen sensation—therefore point to specific molecules and neurons in controlling this evolved behavioral difference. We next examine the ecology of mosquito breeding sites including unmanipulated natural sites and experimental containers. We find that while ancestral-type sites such as tree holes are consistently low in dissolved oxygen (DO), domestic sites are highly variable and often have high DO levels. Thus, there is a concordance between each subspecies' hatching behavior and the aquatic habitats available to it in the wild. Our results suggest the derived domestic form may have diverged from ancestral behavior to exploit breeding sites provided by humans. Hatching behavior presents an opportunity to study the genetic and neural underpinnings of behavioral evolution, and to better understand how animals adapt to built environments in the Anthropocene.

28-4 Middlebrooks, ML*; Nockengost, A; Ambrosio, LJ; University of Tampa; *mmiddlebrooks@ut.edu*

Kleptoplastic sea slug Elysia papillosa prefers algae that provides inferior growth and photosynthesis

Many species of sacoglossan sea slugs are oligophagous, only feeding a few species of closely related algae. Some sacoglossans are also kleptoplastic and can photosynthesize by incorporating chloroplasts taken from their algal food into specialized digestive cells. The duration of photosynthesis varies among species and provides nutritional benefits to the slugs from several days up to many months. *Elysia papillosa* is a small species of sacoglossan ranging through the Caribbean and Gulf of Mexico and can photosynthesize for a short duration after feeding. This slug is associated with algae in the genus *Penicillus*; however, the slug does not use all species of *Penicillus* equally. They are significantly more likely to found on *P. capitatus* than *P. lamourouxii* in mixed algae beds, although they do feed on both algae in the field. Interestingly, slugs feeding exclusively on *P. lamourouxii* grow 1.5-2x larger than slugs feeding on *P. capitatus*. Here we found that slugs were able to maintain active photosynthesis for twice as long when feeding on *P. lamourouxii* compared to *P. capitatus*. We also found that *E.*

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papillosa collected from *P. capitatus* in the field were significantly more likely to travel towards to chemical signals from *P. capitatus* than *P. lamourouxii*, even though they could grow larger and photosynthesize longer if they fed on *P. lamourouxii*. It is unclear why *E. papillosa* chooses algae that provide lesser benefits to growth and photosynthesis. This preference may be due to structural or biochemical defenses provided by the algae against potential predators or the environment. However, additional studies will be required to determine why slugs prefer *P. capitatus*.

75-9 Mielke, F*; Van Wassenbergh, S; Van Ginneken, C; Aerts, P; University of Antwerp; *falk.mielke@uantwerpen.be*

Swing it like a piglet

Terrestrial locomotion necessarily involves a stance phase (to hold the weight) and a swing phase (to advance the stance positions). Of those, the latter is sometimes supposed to be partially passive, i.e. negligible in terms of energy expenditure. For example, the swing phase has been described as "ballistic" (cf. Mochon and McMahon, 1980), which implies that the limb is "shot off" at given conditions, then passively moves, prior to impact. However, such sophisticated locomotor patterns require precise coordination to be energy efficient. There is evidence that young individuals fail to coordinate efficient swings. We present data from locomoting piglets (age 1-5 days) to measure how energy efficient their swing actually is. Using recordings from biplanar x-ray, we are able to quantify inverse dynamic balances and energetics at the joint level in high detail. Our data offers insights into a crucial developmental phase of these animals, showing that "swinging it right" takes some practice.

Reference: Mochon, S. and McMahon, T. A. (1980). Ballistic walking. Journal of biomechanics, 13(1), 49-57. https://doi.org/10.1016/0021-9290(80)90007-X

97-3 Mikel-Stites, MR*; Salcedo, MK; Socha, JJ; Staples, AE; Virginia Tech; *mmikelst@vt.edu*

Three-dimensional imaging of tympanal membranes in a parasitoid fly enables a new model of hearing

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Ormia ochracea is a parasitoid fly known for its extremely precise sound localization abilities, which it uses to locate its preferred host, *Gryllidae* crickets. The model that explains these precise hearing abilities in *Ormia ochracea* may be the only detailed mathematical model of the mechanics of hearing in response to incident acoustic waves in a binaural organism. This model accurately predicts the interaural amplitude difference (ITD) between the tympana for all incident sound angles; however, the model fails to predict the interaural time delay (IAD) accurately for high incident sound angles. To explore the reason for this failure, we used synchrotron radiation microtomography to determine the 3D morphology of the tympana of two *Ormia ochracea* specimens. Previous models assume that these structures operate as 2D-like plates, but imaging reveals that the tympanal structures are complex and three-dimensional in nature. Using this new information to improve the model of hearing in *Ormia ochracea*, we added a term that represents the tympanum's elastic material response in the lateral direction and recovers observed IAD for all incident sound angles. This work demonstrates that hearing in *Ormia ochracea* involves acoustic information and physiological responses in two primary planes, rather than one. It is possible that this improved model may be useful in the design of improved microscale auditory devices, including several insect-inspired directional microphones and hearing aids.

61-6 Miles, DB*; Snell, HL; Snell, HM; Stone, PA; Ohio University, University of New Mexico, University of Central Oklahoma; *urosaurus@gmail.com*

Morphological and performance consequences of hybridization between marine and land iguanas

Research on the ecology of hybridization has often emphasized the deleterious consequences on fitness. Selection against hybrids is assumed to reinforce reproductive isolation among incipient species. However, recent data has demonstrated hybridization may enhance diversity by generating novel phenotypes. Although a substantial body of research has focused on life history differences between hybrids and parental species, limited data are available on functional traits that may affect how hybrids exploit resources or evade predators. Female marine iguanas and male land

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iguanas are known to hybridize on Isla Plaza Sur, Galapagos. We measured morphology and performance traits of hatchling hybrid marine iguanas (*Amblyrhynchus cristatus*) x land iguanas (*Conolophus subcristatus*), and the parental species. We estimated their stamina by inducing them to run on a treadmill until exhaustion. We also obtained measurements for 7 morphological traits. Hybrid iguanas were smaller and lighter than hatchlings of either parental species. Hatchling marine iguanas were the heaviest. Hatchling iguanas also differed in limb and tail lengths from the parental species. The performance trials demonstrated that hybrid hatchlings exhibited greater stamina than either parental species; hatchling marine iguanas were capable of longer sustained movement than land iguanas and appeared more similar to hybrid hatchlings. Our results show that hybrids are smaller in multiple external traits, yet have enhanced performance capacities. Hybrids tend to be more similar in functional traits to marine iguanas than land iguanas, suggesting a possible maternal influence in morphology. However, higher values of physiological performance are indicative of a novel phenotype, which would not be predicted by morphology.

91-7 Miller, CL*; Dugand, R; Franklin, CE; McGuigan, KM; University of Queensland; *christina.miller@uqconnect.edu.au*

Using the effect of new mutations to better understand the genetic basis of thermal sensitivity

How populations respond to novel or rapidly changing environmental conditions depends, at least in part, on how fitness effects of alleles change with the environment. Variation in the effects of alleles across environments could result in greater genetic variation, and potentially facilitate rapid adaptation enabling evolution to keep up with the current environmental changes. However, we know relatively little about how allelic effects vary, and in particular how such variation affects evolvability across environmental gradients. To address this question, we introduced new alleles, unsorted by historical selection, into a population of zebrafish, *Danio rerio*, using the mutagen ENU. We characterised the effect of this new mutational variance on swimming performance across a thermal gradient to test the hypothesis that mutational effects vary with temperature in such a way as to increase genetic variation in environments that are increasingly different to the

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historically experienced environment. Swimming speed was genetically correlated across temperatures, with the most mutational variance associated with faster/slower swimming speeds across all temperatures. This suggests selection could act on this axis of variation to remove slow individuals from the population. We did not observe support for the hypothesis that mutational effects were smallest in the ancestral temperature, but rather that mutational effects of swimming speed vary little over an ecologically relevant temperature range in zebrafish.

S1-11 Miller, CR*; Vitousek, MN; Thaler, JS; Cornell University; *ccm246@cornell.edu*

Artificial light at night disrupts trophic and population dynamics of lady beetles and pea aphids in cool conditions

Natural variation in light has historically correlated with seasonal changes in temperature, providing an honest cue to organisms with seasonal life history cycles. However, with the onset of widespread artificial light at night (ALAN), light is no longer reliably associated with changes in temperature, leading to altered behavior under different environmental conditions. We experimentally investigated impacts of cool temperature and constant light on a lady beetle-aphid-fava plant system to ask 1) how do contrasting temperatures and light influence aphid population growth? and 2) what are the behaviors underlying impacts on this common assemblage's dynamics? First, we investigated direct effects of treatments on predator (*Coccinella septempunctata* and *Coleomegilla maculata*) feeding behavior, aphid predator evasion tactics, aphid population dynamics and plant growth. We then assessed the net effects of ALAN on aphid (*Acyrthosiphon pisum*) population growth by manipulating temperature and light cycles of our tri-trophic interaction over a ten-day period. Overall, we found that ALAN had multidirectional effects which vary in prevalence under different temperature regimes. Aphids had high population growth rates in cooler treatments, a potential impact of negative density-dependent growth patterns we tracked with and without predators. Aphids and predators reacted differently to variation in light and temperature: we observed evidence of bottom-up food web impacts as aphids excelled in cool, light conditions, and we found top-down control of aphids was

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strengthened by heightened predatory success in warm conditions, particularly under non-constant light. This knowledge may impact how scientists manage common insect pests during different times of year under the brightening night sky.

5-2 Miller, CW*; Emberts, Z; Chen, S; Wilner, D; Woodman, TE; Federle, W; Univ. Florida, Univ. Cambridge, Univ. Cambridge; *cwmiller@ufl.edu*

Adult nutrition affects the defensive performance of an insect weapon

Animal weapons commonly must resist large loads and impacts generated by pushing, striking, and even twisting. The performance of weapons can be central to male reproductive success; yet, not all weapons can weather the battle. Few studies have investigated the influence of nutrition the stability of the weapon structure. We focused on the effects of adult nutrition on the insect weapon, something previously not examined in any of the millions of species of insects and other arthropods. The lack of studies in this area may seem obvious; when an insect molts into adulthood, its weapon skeleton hardens and retains the same external size and shape for life. However, this static exterior may hide significant changes on the inside. In this study, we focused on the effects of early adult nutrition on weapon integrity using the leaf-footed cactus bug, *Narnia femorata* (Hemiptera: Coreidae). Males of *N. femorata* use their enlarged and spiny hind limbs to strike and squeeze other males in competition over reproductive opportunities. We found that just three weeks of high-quality adult nutrition resulted in 82% greater puncture resistance of the hind leg weapon than the weapon of those with poor-quality nutrition. The higher puncture resistance was correlated with a significant increase in skeletal (cuticle) mass; high-quality nutrition led to a 125% greater cuticle mass of the hind leg. Our results demonstrate that adult nutrition may be a vital unexplored factor influencing weapon performance during battle. Our findings also highlight that external size may be deceiving and may not always serve as an honest signal of performance.

8-2 Miller, AE*; Hogan, BG; Stoddard, MC; Princeton University,

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Color in motion: Using photogrammetry to study dynamic displays in virtual environments

Animal signals are often complex and dynamic, but it can be challenging to measure all aspects of a signal simultaneously. Recent advances in imaging technologies, along with increased integration of behavioral ecology and computer science, provide new opportunities to analyze and interpret the color, pattern, and motion of animal displays in a more comprehensive way. By combining multispectral imaging with photogrammetry and 3D animation, we have devised a pipeline for analyzing colorful animal displays in a virtual environment. This type of approach has two major benefits. First, it adds extra dimensions, space and time, to traditional analyses of color and pattern. Second, it allows us to manipulate the conditions under which a signal is being observed. To accomplish this, we used a modified camera to capture UV and human visible color information from a mounted specimen of a colorful bird, the Hooded Pitta (*Pitta sordida*). Using the photogrammetric technique Structure from Motion, we generated a 3D model embedded with the UV and visible color information. We then animated the model in 3ds Max based on known behaviors exhibited by *P. sordida* . Renders of the animation were then used to analyze plumage color in the context of motion and the perspective of the intended observer. By developing cross-disciplinary methods that combine the measurement of color, pattern and motion, we will be better positioned to investigate dynamic displays and to understand the evolutionary forces that shape these signals as a whole.

85-4 Miller, K*; Fuentes, P; O'Brien, DM; Angelini, DR; Colby College; *kamill21@colby.edu*

Variation in the evolution and expression of phenotypically plastic structures

Phenotypic variation is determined by both additive genetic variation and an organism's environment. Many studies have measured patterns of selection acting on phenotypes where the majority of variation is the result of additive genetic variance. Fewer, however, have measured patterns of selection acting on traits where the majority of phenotypic variation is determined by the

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environment. In this study, we measured several factors that contribute to the expression of environmentally-determined phenotypically plastic structures and compared them across species, populations and structures to better understand the ways in which common, highly plastic structures respond to selection. We provide data for two emerging model systems- the red-winged soapberry bug *Jadera haematoloma* and the broad-horned flour beetle *Gnathocerus cornutus*. Both organisms have highly plastic traits where the majority of phenotypic variation is determined by the organism's developmental environment. *J. haematoloma* displays a wing polyphenism where the size and shape of wings are dependent on the type and quality of the organism's host plant. *G. cornutus* bears highly plastic sexually selected mandible weapons where weapon size is determined by the nutritional environment during critical points in development. We measured traits that were environmentally regulated (mandibles/wings) as well as traits that exhibit more patterns in development (eyes/beak). Overall, our results provide critical insight into how highly plastic environmentally regulated structures and structures with relatively low heritability evolve ultimately contributing to holistic comprehension of morphological diversity and evolution in general.

50-2 Min, Y*; Imani, JI; Kramer, EM; Department of Organismic and Evolutionary Biology, Harvard University, Cambridge, MA; *yamin@g.harvard.edu*

Sweet genes are made of STYLISH - Members of the STYLISH gene family control both style and nectary development in Ranunculids

The presence of floral nectaries is a particularly interesting example of convergent traits in flowering plants and is considered to be associated with the adaptation and diversification of numerous angiosperm lineages. For instance, the petal spurs of Aquilegia flowers are regarded as a key innovation, but the adaptive radiation of the New World Aquilegia species would have been unlikely to have occurred if there were no nectaries at the distal tips of the petal spurs to reward pollinators. To date, we have very little knowledge of what genes contribute to nectary development and evolution, particularly in non - core eudicot taxa. In this study, we investigated the functions of genes from the STYLISH (STY) family in A. coerulea. Single and triple gene

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knockdown revealed that these three genes function redundantly in style and nectary development, and triple silencing led to the absence of nectary. No previous study among the core eudicot has reported STY genes to function in nectary development, suggesting the genes have been co - opted to this role in Aquilegia. Moreover, strong expression of STY homologs in nectary - bearing petals has also been detected in Delphinium and Epimedium, suggesting that this co - option event is likely to have occurred before the diversification of the family Ranunculaceae and Berberidaceae. Since the identification of the first gene controlling nectary development in 1999, the STY homologs of the Ranunculaceae are the only alternative loci for the control of nectary development in flowering plants, providing a critical data point in understanding the evolutionary origin and developmental basis of nectaries.

93-12 Mishra, A; National Center for Biological Science, Bangalore, India; *aditi.niser@gmail.com*

The innate floral template of a generalist pollinator

For pollinators, identifying flowers is essential for survival. But how do pollinators distinguish flowers from other objects in a world inundated by visual and olfactory cues. Further how do they distinguish suitable flower from all available flowers? And how do solitary generalist pollinators do that within hours of emergence? They identify the flowers with accessible floral rewards within a few hours of emergence with no learning or memory of flowers, and no social cues. This is no trivial task. To understand the algorithms behind this hard identification task that pollinators perform seamlessly, we explored the innate floral choices of the generalist pollinator *Eristalinus aeneus* . *Eristalinus aeneus* are robust, cosmopolitan, and solitary pollinators. They are found in diverse biomes and floral niches across the world. By employing a combination of field and laboratory observation, chemical and visual analysis, and 3-D printing techniques, we identified an object consisting of a few olfactory and visual cues attractive to multiple hoverflies, including E. aeneus. E. aeneus perform directed flights, slow down, hover, land and extend proboscis to this artificial flower in a manner similar to real flowers. By sequentially perturbing the visual and olfactory cues of this artificial flower, we find that naïve Eristalinus aeneus use a

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simple multimodal template to find flowers. Flies require olfactory cues to identify flower objects, but visit a wide range of contextual odors equally. Naïve hoverflies also show a small preference for flower shape and a high preference for brightness and reflectance in the greenish-yellow spectral range (540-580 nm). Combined, these seemingly general cues are broad enough to help these pollinators visit and forage from several classes of flowers but are specific enough to reject non-floral objects.

96-7 Mitra, AT*; Womack, MC; Gower, DJ; Clark, B; Streicher, JW; Bell, RC; Schott, RK; Fujita, MK; Thomas, KN; University College London, Natural History Museum, London, UK, Utah State University, Logan, USA, Natural History Museum, London, UK, Natural History Museum, London, UK, California Academy of Sciences, San Francisco, USA, York University, Toronto, Canada , University of Texas, Arlington, USA; *amartya.mitra@nhm.ac.uk*

Lens morphology is influenced by ecology in frogs and toads (Amphibia: Anura)

Lens morphology is an important aspect of vertebrate visual biology. Lens shape is typically more spherical in aquatic vertebrates (lenses) and flattened in terrestrial species to facilitate vision in different optical media. Anurans (frogs and toads) are an ecologically diverse amphibian order, with many species undergoing a shift from aquatic to terrestrial lifestyles during metamorphosis. However, the nature and extent of lens shape and size variation has not been examined over a broad phylogenetic and ecological range of species. We quantified lens shape and size using 170 CT scans of 123 anuran species across 40 of the 55 currently recognised families. Our study found that lens morphology is correlated with life stage and general ecology in anurans. Aquatic anuran larvae have spherical lenses, which are retained after metamorphosis in species with aquatic and fossorial adults. In contrast, species with 'above ground' terrestrial adult ecotypes, typically have more flattened lenses as adults. This study demonstrates the impact of optical media and light conditions on the evolution and development of anuran lenses and highlights the usefulness of CT data and museum specimens for studying the morphology of visual systems in vertebrates.

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52-1 Miyamae, JA; Yale University; *juri.miyamae@yale.edu*
Sleepy gapes caught on tape: Mammalian nasal proboscis position during yawning based on an analysis of YouTube videos
Yawning behavior has been widely observed among extant vertebrates and the behavior has been associated with a variety of different stimuli such as sleepiness, stress, or social displays. The large, exaggerated mouth gape characteristic of yawning distorts the soft tissues of the face in mammals, including the facial muscles. The facial muscles of the upper lip and snout are responsible for the movement and structural composition of the elongated, mobile nasal proboscis found independently in multiple lineages of mammals including sengi (Macroscelidea), elephants (Proboscidea), solenodon (Eulipotyphla, Solenodontidae), desmans (Eulipotyphla, Talpidae), tapirs (Perissodactyla), and saiga antelope (Artiodactyla). Despite the repeated evolution of a mobile nasal proboscis, there is considerable diversity in the muscular anatomy, internal support structures, and overall morphology of these appendages which may be reflected in behaviors such as yawning. Using categorical scoring of the movement and position of the proboscis during yawning in video recordings, I found little intraspecific variation, but notable differences between species, even among relatively closely related taxa: e.g., between members of the sengi subfamily Rhynchocyoninae yawning with a "snout down" position versus subfamily Macroscelidinae yawning with a "snout up" position. In this study, I present a characterization of the morphological diversity of mammalian nasal probosces, their potential impact upon yawning behavior, and the use of the online video sharing platform YouTube, a rich and relatively untapped source of publicly-accessible data on animal behavior and function.

55-3 Miyashita, T*; Baddam, P; Smeeton, J; Oel, AP; Natarajan, N; Gordon, B; Palmer, AR; Crump, JG; Graf, D; Allison, WT; Canadian Museum of Nature, Ottawa, University of Alberta, Edmonton, Columbia University, New York, European Molecular Biology Laboratory, Heidelberg, University of Southern California, Los Angeles; *tmiyashita@nature.ca*
Agnathan-like heads of functionally jawless zebrafish

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In vertebrates, a functional jaw apparatus requires a hinge joint, so jaw joint defects are often highly disruptive. To describe the consequences of jaw-joint dysfunction, we engineered two independent null alleles of a single jaw-joint marker gene, *nkx3.2*, in zebrafish. These mutations caused zebrafish to become functionally jawless via fusion of the upper and lower jaw cartilages. Despite their jaws being locked, *nkx3.2* mutants accommodated this defect by: a) having a remodelled skull with a fixed open gape, reduced snout, and enlarged branchial region; and b) performing ram feeding in the absence of jaw-generated suction. The late onset and broad extent of phenotypic changes in the mutants suggest that modifications to the skull are induced by functional agnathia, secondarily to *nkx3.2* loss-of-function. Interestingly, *nkx3.2* mutants superficially resemble ancient jawless vertebrates (anaspids and thelodonts) in overall head shapes. Because no homology exists in skull elements between these taxa, the adult *nkx3.2* phenotype is not a reversal, but convergence due to similar functional requirements of feeding without moveable jaws. This remarkable analogy makes the mutants a unique model with which to: a) investigate adaptive responses to perturbation in skeletal development; b) re-evaluate evolutionarily inspired interpretations of phenocopies generated by gene knockdowns and knockouts; and c) gain insights into feeding mechanics of the extinct agnathans.

94-5 Mo, A*; Kamska, V; Contreras, FB; Daley, M; Badri-Spröwitz, A; MPI for Intelligent Systems, Stuttgart, University of California, Irvine; *mo@is.mpg.de*

Developing a mechanical model for intraspinal mechanosensing in avians

The lumbosacral (LS) spine region in birds shows unique modifications: a high-density glycogen body, wedged between both spinal cord hemispheres, supported by a accentuated denticulate ligament network, accessory lobes, surrounded by spinal fluid inside an expanded canal with semicircular grooves. Evidence for mechanosensing capabilities of accessory lobes indicates a 'lumbosacral organ'. Previous hypotheses considered intraspinal sensing of fluid-flow, pressure, or strain. Based on our own observations of potential for soft tissue movement inside the LS

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region (Kamska et al, in review), we consider the option of strain-based sensing caused by tissue deformation. Body movements would accelerate LS soft tissue, causing elastic deformations sensed by accessory lobes. Due to insufficient access to the LS soft tissues in vivo, we are now implementing a mechanical simulator to study the putative LS mechanosensing function. Based on the morphology of quails we developed an LS phantom. It contains the spinal cord's simplified stand-ins; spinal fluid, glycogen body, spinal canal, and spinal cord with denticulate ligaments. A mechanism moves the LS phantom, similar to movements caused by legged locomotion, and a camera records the resulting soft tissue oscillations. This model will allows us to characterize the potential for physical interactions between the LS soft tissue and bony canal, to understand the sensitivity characteristics of the putative LS sensing organ.

93-2 Mobley, RB*; Boughman, JW; Michigan State University; *mobleyro@msu.edu*

The sensory space of the threespine stickleback

The peripheral sensory systems, whose morphological attributes help determine the acquisition of distinct types of information, provide a means to quantitatively compare multiple modalities of a species' sensory ecology. We used morphological metrics of the visual, olfactory, and mechanosensory lateral line sensory systems of Gasterosteus aculeatus, the threespine stickleback, to compare how sensory systems vary in animals that evolve in different ecological conditions. We hypothesized that the dimensions of sensory organs and correlations among sensory systems vary in populations adapted to marine and freshwater environments, and have diverged further among freshwater lake-dwelling populations. Our results showed that among environments, fish differed in which senses are relatively elaborated or reduced. When controlling for body length, littoral fish had larger eyes, more neuromasts, and smaller noses than pelagic or marine populations. We also found differences in the direction and magnitude of correlations among sensory systems for populations even within the same habitat type. We conclude that visual, olfactory, and lateral line systems differ among populations, although not in accord with these broad categorizations of habitat

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83-1 Monette, MY*; Velotta, JP; Western Connecticut State University, Danbury, CT, University of Denver, Denver, CO; *monettem@wcsu.edu*

Gill transcriptomic response to seawater is altered by acute stress in Atlantic salmon smolts

The transition from freshwater to seawater is an extreme physiological challenge for Atlantic salmon smolts. Stressors occurring during downstream migration impair the ability of smolts to maintain ionic/osmotic homeostasis in seawater, however the molecular mechanisms underlying this are not fully understood. We used RNA-seq and measures of whole animal performance to examine the molecular basis of impaired seawater tolerance after an acute aquaculture-related stressor. Smolts were challenged with 24h of seawater before and after exposure to acute netting/confinement stress. RNA-Seq followed by Differential Expression and Weighted Gene Co-expression Network Analysis (WGCNA) was used to quantify the transcriptional response of the gill to netting/confinement stress, seawater, and their interaction. Netting/confinement impaired seawater tolerance, as indicated by increases in plasma osmolality and chloride in stressed smolts as compared to controls. Exposure to netting/confinement stress, seawater, and their interaction resulted in 2717, 1007, and 1390 differentially expressed genes, respectively, indicating a different profile of transcriptional activity in the gill under each condition. WGCNA identified 15 modules (groups of co-expressed genes), 10 of which were correlated to one or more performance traits: glucose, chloride, and osmolality. Two-way ANOVA revealed that 7 modules were significantly affected by stress, 6 by seawater, and 2 by their interaction. These data suggest that acute stressors cause rapid shifts in the magnitude and direction of gene expression in the gills of smolts that persist during early seawater acclimation. Future work will include analyses to explore the functional significance of differentially expressed genes and modules.

S6-10 Mongeau, JM; Penn State University; *jmmongeau@psu.edu*

Orientation control via spatiotemporal integration in fly flight

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The ability of animals to orient in space and localize features is essential for survival, including communicating with conspecifics, finding food or escaping from a predator. Among these, flying insects must coordinate head and body movements to direct gaze towards a feature of interest. As in humans, gaze shifts in flies are punctuated by ballistic maneuvers termed "body saccades". By studying fly flight in virtual reality, we characterized how body saccades are influenced by visual spatiotemporal dynamics. We discovered that the spatiotemporal dynamics of features across the retina are integrated to trigger a saccade. Visual object span drives two distinct classes of saccades: one class tuned to object speed (object-tracking saccade) and another tuned to overall optic flow (optomotor saccades). The proportion of smooth and saccadic movement is influenced by the object span, background type, contrast, and texture. A mathematical hybrid control model that implements spatiotemporal integration provides a simple algorithm for tuning saccades in flight. For visual spatial orientation control in fly flight, we propose a control hierarchy that includes a low-level, inner-loop optomotor reflex that control body velocity and a mid-level, outer-loop saccade movement primitive that controls body position.

27-1 Monroe, DM*; Offermann, G; Gabor, CR; Texas State University; *djm261@txstate.edu*

Exposure to warmer water, but not pond drying as tadpoles contributes to decreased survival when exposed to fire ants

Organisms with complex life cycles, such as amphibians, are particularly sensitive to the changes associated with urbanization and are often the first to be extirpated. Ecosystems that are urbanized experience many alterations including greater fluctuation in water levels, higher temperatures, and an increase in invasive species. One common invasive in the urbanized southern United States is the Red Imported Fire Ant (*Solenopsis invicta*; RIFA). For newly metamorphosed amphibians, ants comprise a significant amount of their diet. When an amphibian metamorph tries to eat a RIFA, the predator can quickly become the prey. In Texas, the Gulf Coast Toad (*Incilius nebulifer*) is one of the only amphibians that appear to be increasing in abundance and distribution. To investigate their success, we tested the growth and survival of *I. nebulifer* tadpoles

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exposed to two different water levels (high and low) and two different water temperatures (31° C and 23° C). We then tested for a carry-over effect after metamorphosis by exposing tadpoles to RIFA periodically throughout their early post metamorphic development and measured survival and growth post-metamorphosis. Tadpoles raised in 31° C water grew faster than 23° C water. All metamorphs exposed to RIFA had decreased survival, and metamorphs that were raised in 31° C water as tadpoles had the greatest decrease in survival after exposure to RIFA. Although warmer water allowed tadpoles to grow faster, they were ultimately more susceptible to succumbing to the stress caused by RIFA encounters. Even for a species that appears to have adapted well to urban living, urbanization still poses a high risk to survival.

104-4 Montuelle, SJ*; Olson, R; Gerstner, G; Curtis, H; Williams, SH; Ohio University Heritage College of Osteopathic Medicine, Center for Research and Interdisciplinarity Paris, University of Michigan School of Dentistry; *montuell@ohio.edu*

Time-shifting correlations in jaw-tongue coordination during feeding in pigs

Feeding is an integrative behavior that requires movements of the jaw to bring the teeth into contact with the food, while the tongue moves and deforms to position and manipulate the food bolus. Jaw and tongue movements during feeding have both been studied extensively, but usually separately and at specific time points within the gape cycle (minimum gape, maximum tongue protrusion). In comparison, jaw-tongue coordination has mostly been described qualitatively and only quantified at the level of the feeding sequence. Here we measured jaw-tongue coordination by testing the correlations between jaw movements and tongue kinematics continuously throughout the gape cycle. First, using XROMM, jaw pitch (opening-closing), tongue protraction-retraction, width, length and surface area were reconstructed in 7 pigs chewing on 2 different foods (apples and almonds). Then, using Functional Data Analysis, we standardized and resampled the kinematic waves and tested the bivariate correlations between jaw pitch and tongue kinematics at each timestamp, thus identifying when coordination is strongest, and when it is weakest. Our results show that each tongue variable has a different pattern of coordination with jaw

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opening-closing movements. The strength of the correlation is also not constant through time, but instead shifts between periods of strong correlation and periods of low, non-significant correlation. In both foods, jaw-tongue coordination is the strongest around maximum gape, but food-specific time-shifts in the coordination pattern occur during tooth-food-tooth contact.

1-6 Moon, HE*; Porter, ML; University of Hawai'i at Mānoa; *hmoon@hawaii.edu*

A seabird's eye view of artificial light and the moon

Artificial lights at night cause high mortality in fledgling seabirds due to attraction and subsequent grounding, particularly during the new moon. Previous studies on migratory birds suggest that the color of artificial light can affect attraction, but the drivers behind this behavioral phenomenon are poorly understood. It is known that the number of grounded fledgling seabirds, such as the Wedge-tailed shearwater (*Ardenna pacifica*), fluctuates with the moon. To investigate visual cues that may be driving observed light attraction behavior, visual contrast models were created using the PAVO R package. Using published data on both the visual system of *A. pacifica* and the spectra of common streetlights, we investigated how the color contrast of the moon and artificial lights compare, and how *A. pacifica* perception may differ from human perception. Results suggest humans are more easily able to detect differences in color between artificial lights and the full moon than *A. pacifica*. Results also suggest that to seabirds, many artificial lights look similar in color to the full moon. These results are consistent with behavioral tests of seabird attraction to a variety of common streetlights and have implications for conservation management of artificial light near seabird colonies.

BSP-9-1 Moore, CL*; McDonnell, AJ; Schuette, S; Martine, CT; University of Pittsburgh, Chicago Botanic Garden, Western Pennsylvania Conservancy, Bucknell University; *clm223@pitt.edu*

Granivory impacts on the Pennsylvania threatened species Baptisia australis var. australis (Fabaceae)

The perennial wildflower, *Baptisia australis* var. *australis* (L.) R. Br. is found along only four waterways in Pennsylvania, and it is

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because of this limited distribution and small number of extant populations, that *B. australis* var. *australis* is considered state-threatened in Pennsylvania. In addition, the riparian prairie habitat that Pennsylvania *Baptisia australis* var. *australis* is restricted to is also in decline and considered vulnerable in the state. Because of conservation concerns for *Baptisia australis* var. *australis* in Pennsylvania, gaining insights into the natural history of the taxon is useful for conservation practitioners to understand the extent of threats facing the taxon. While granivory by several insect species is noted to impact the taxon in other parts of its range, no granivory has been recorded in Pennsylvania. Field survey and examination of herbarium specimens were used to determine if granivores are present in Pennsylvania populations. Once evidence of granivory was found, field collected data and generalized linear models were used to further analyze the impact of granivores, as well as attempt to determine if there are factors that could be used to help predict granivore presence/impacts. Through partnership with various Pennsylvania conservation agencies, this research will help to inform the future conservation status of *Baptisia australis* var. *australis* in Pennsylvania, and finally provide evidence that granivores do impact Pennsylvania *B. australis* var. *australis* populations.

S12-1 Moore, IT*; Jones, BC; Virginia Tech, Bennington College; *itmoore@vt.edu*

Manakin genomics: comparative studies of evolution and behavior in a unique clade of birds

In this symposium, we will present much of the work done as part of the Manakin Genomics Research Coordination Network (Manakin Genomics RCN, https://www.manakinsrcn.org). This RCN has brought together researchers from across disciplines to address the implications of sexual selection on evolution, ecology, behavior, and physiology using a clade of unique neotropical birds, the manakins. The manakins are a great example of sexual selection as nearly all of the 51 species are lek-breeding and highly sexually dimorphic. Males display elaborate vocal as well as visual courtship behaviors which are often highly acrobatic. In some cases, males exhibit cooperative displays. Males also exhibit

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unique neuroendocrine and physiological adaptations that underlie these behaviors. This symposium will highlight the remarkable genomic, behavioral, and physiological adaptations as a consequence of strong sexual selection pressures that are evident in manakins.

3-1 Mordvinov, Y*; Peters, KD; Gonzalez, MS; Müller, UK; Reece, JS; CSU Fresno; *umuller@csufresno.edu*
Trap morphology in the carnivorous plant genus Utricularia
Bladderworts (genus *Utricularia*) are a diverse genus of carnivorous plants with over 230 known species. They inhabit a wide range of geographic locations and habitats, and have evolved a highly derived and variable morphology to match. Their traps can make up a majority of the plant's biomass, representing a considerable investment by the plant into carnivory. We hypothesize that bladderworts have adaptations to increase the traps' effectiveness, such as structures that increase encounter probability with profitable prey, or decrease fouling or misfiring. We hypothesize that trap morphology will vary according to habitat and consequently available prey types. We defined morphological traits to assess morphological variation between species as a function of habitat. We described the structures at the trap entrance, trap size, and attachment point of the trap to the rest of the plant. To better understand how *Utricularia* have adapted across terrestrial and aquatic habitats we categorized morphological data of the plants against ecological covariate data, while correcting for phylogenetic signals. This study might facilitate future studies into how bladderworts have optimized their traps to overcome obstacles to predation in their respective environments.

S7-4 Morehouse, NI; University of Cincinnati; *colorevolution@uc.edu*
Colors as life history traits: Insights from the pigment-based coloration of two butterfly species
Animal colors, once thought to evolve strictly on the basis of their semiotic value, are now known to impose often-significant material costs. For example, many red, orange, and yellow avian colors rely on substantial inputs of diet-derived carotenoids. This has led researchers to ask whether color evolution might reflect material tradeoffs between colors and other traits, such as

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immunocompetence or oxidative stress tolerance. However, mechanistic support for such connections has often been elusive, even in well-studied systems such as avian carotenoid coloration. This may be due in part to life history characteristics of focal taxa, where researchers have often favored the study of income breeders. Income breeders fund the costs of reproduction, including sexually selected colors, via a mix of past and current income, thereby making supply-and-demand connections more challenging to resolve. Here, I discuss insights into the material basis and evolution of bright coloration from two capital breeding butterflies: *Pieris rapae* and *Araschnia levana*. In *P. rapae*, dietary protein limitations during larval development force tradeoffs between pterin-based adult male coloration and a variety of other reproductive and non-reproductive traits. The result is deep integration between color and other life history traits, which helps to explain why these colors have evolved under female choice as indicators of male quality. In contrast, the evolution of ommochrome-based seasonal color polyphenism in *A. levana* has been shaped not by scarcity, but rather by a need to cope with the toxic/hormone suppressant effects of ommochrome precursors. Taken together, these case studies highlight the utility of studying capital breeders when investigating the evolutionary consequences of the material basis for animal colors.

57-1 Moretto, WI*; Stahl, AK; Mehta, RS; University of California, Santa Cruz; *wmoretto@ucsc.edu*

Effects of acute temperature change on the feeding behaviors of Gymnothorax mordax

California moray eels, *Gymnothorax mordax*, are benthic predatory residents of the southern California kelp forests. For a predatory fish, morays have a relatively large repertoire of prey handling behaviors that enable them to manipulate their prey and force prey into their mouths before swallowing. Prey manipulation behaviors include shaking, spinning, knotting, and ramming prey against other objects. We varied water temperatures for captive morays to mimic the temperatures they encounter throughout their range, seasonal variation, and potential fluctuations they experience throughout the water column. We hypothesize that higher temperatures will increase the prevalence of whole body prey manipulation behaviors.

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Five morays were acutely exposed to four treatment temperatures and their subsequent feeding behaviors were filmed and quantified. Individuals were offered the same relative prey mass (15%) in relation to their body mass. We compared the mean time spent in each behavior and relative proportions of behaviors across the different temperatures. Our data demonstrates that absolute time spent employing all four prey manipulation behaviors varies significantly across temperature, as does the proportion of time spent utilizing different behaviors. For example, in the coolest temperature, ramming was most common, while at the warmest temperature, knotting was more frequent. Rates of behaviors varied irrespective of temperature. Shaking always occurred at a significantly higher rate while knotting occurred at a slower rate. Understanding the environmental factors that affect the feeding response of predators has major implications on predator-prey relationships in the marine community.

87-10 Morisawa, R*; Derkarabetian, S; Boyer, SL; Macalester College, Saint Paul, MN, Harvard University, Cambridge, MA; *rina.morisawa1@gmail.com*

Phylogeny and biogeography of the New Zealand mite harvestman genus Rakaia, based on ultraconserved elements (UCEs)

We conducted phylogenomic analyses of *Rakaia*, a genus of mite harvestman (Arachnida, Opiliones, Cyphophthalmi) from New Zealand, based on sequence capture of ultraconserved elements (UCEs), which are exonic in origin in arachnids. *Rakaia* is the most speciose and widespread mite harvestman genus in New Zealand. Previous efforts to understand phylogenetic relationships within this group have used a standard Sanger sequencing approach, and have been restricted in terms of taxonomic sampling and number of loci sequenced. UCEs target capture allowed sequencing of several important historical museum specimens, which was not possible with Sanger sequencing due to DNA degradation. We sequenced UCEs from forty-seven *Rakaia* specimens belonging to seventeen named species and six undescribed species, in a first attempt at using next-generation sequencing techniques for New Zealand mite harvestmen at the species level. Morphological and geographical data were used integratively with our phylogenomic results to identify four new species; we successfully included a thirty-five-year-old specimen

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in our phylogeny, and monophyly was supported in two putative new species. We discuss ways in which we could improve this phylogeny, namely the use of more individuals per species, refined post-sequence analyses, and the development of a clade-specific probe set. We identify future directions for utilizing these high-resolution phylogenies based on UCEs to test long-disputed biogeographical hypotheses in the context of Gondwanan vicariance.

18-7 Morrell, A*; Bartlam-Brooks, H; Bennitt, E; Webster, J; Wilson, A; Structure and Motion Lab, The Royal Veterinary College, London, UK, Okavango Research Institute, University of Botswana, Centre for Emerging, Endemic and Exotic Diseases, The Royal Veterinary College, London, UK; *amorrell@rvc.ac.uk*

Using dead reckoning to identify fine scale movements of navigating zebra in Botswana, Africa

Zebra in the Makgadikgadi Pans National Park (MPNP), Botswana, repeatedly travel between grazing grounds and a single river water source during the dry season (April-October). Trajectories are highly directed and consistently straight, suggesting zebra can orient themselves accurately over 20km from the river and maintain precise position updates throughout their journey. Given the distances and homogeneity of the landscape it is unlikely a single visual or olfactory cue triggers the orientation and tortuosity of the route taken. Obtaining high frequency GPS data to elucidate decision making processes behind subtle changes in orientation, for example, would consume too much power for a wildlife collar to maintain over time. Integrating gyroscope and magnetometer data, known as dead reckoning, can give a more accurate idea of where the animals have travelled but accumulates drift. Combing both 5-minute GPS fixes and dead reckoning data, we demonstrate whether a continuous, drift corrected path can elucidate navigational strategies by identifying fine-scale movements for zebra in the MPNP. These preliminary data, coupled with ongoing analysis, provide crucial insights into how zebra, and potentially other migratory mammals, maintain efficient and precise travel in hostile environments with limited external stimuli, aiding conservation efforts in the MPNP and elsewhere.

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68-9 Morris, JS*; Link, J; Martin, JC; Carrier, DR; Wofford College, University of Utah; *morrisjs@wofford.edu*

Powering a punch: Male-biased sexual dimorphism in human fist-propelling performance

Humans often use the fist as a weapon when fighting. Previous work has shown that forming a buttressed fist decreases the risk of injury that may occur when striking an opponent. Sexual dimorphism can evolve when enhancement of specific musculoskeletal traits improve the effectiveness of using a weapon. We tested the hypothesis that selection on male fighting performance in humans is associated with sexual dimorphism in the musculoskeletal system that powers using the fist as a weapon. We measured arm cranking power output in males and females using an inertial load ergometer. We used forward arm cranking as a proxy for the power production component of striking with a fist and backward arm cranking as an unselected control. Our results show pronounced male-biased sexual dimorphism in power production for protracting the arm to propel the fist forward. Sexual dimorphism was greater in forward arm cranking than backward arm cranking, supporting the hypothesis that humans exhibit male-biased sexual dimorphism in the components of the musculoskeletal system that provide the power for throwing a punch. We also measured overhead pulling force in order to test an alternative hypothesis that sexual dimorphism in the upper body of humans is a result of selection on male overhead throwing ability. We found weaker support for this hypothesis, with less pronounced sexual dimorphism in overhead arm pulling force. These results provide further support for the hypothesis that sexual selection on male aggressive performance has played a role in the evolution of the human musculoskeletal system and the evolution of sexual dimorphism in hominins.

3-6 Mosher, A*; Papaj, D; Buchmann, S; Eltz, T; Russell, A; Missouri State University, University of Arizona, University of Bochum; *abilene703@live.missouristate.edu*

No trick anthers: buzz pollination behavior is elicited, but likely not manipulated, by anther chemical cues

Flowering plants often manipulate the foraging behavior of their pollinators to exploit them. For example, flowers might produce cues facilitating pollen pickup by pollinators,

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while simultaneously reducing their foraging effectiveness. Generalist bees foraging on flowers frequently use a pollen foraging behavior termed floral sonication, which involves vigorous vibration of the anthers. By manipulating the intensity or occurrence of floral sonication (associated with pollen collection), a flower might exploit the bees to collect less pollen than would benefit it. We therefore tested how chemical cues associated with the anthers (the male flower reproductive parts) mediated floral sonication by the generalist bee, *Bombus impatiens*. We found that floral sonication was elicited by anther chemical cues (crude solvent anther extracts). Surprisingly, the intensity of floral sonication (measured in decibels) and its occurrence was not affected by the concentration of anther chemical cues applied to flowers, even at very weak concentrations. Our results also suggest that anther chemical cues eliciting sonication are of low volatility: sonication was elicited to a similar degree by extracts left to volatilize on artificial anthers for different controlled lengths of time. In ongoing work, we are assessing the threshold strength of the chemical cues eliciting floral sonication to facilitate their identification. Altogether, our results suggest that while chemical cues are key elicitors of floral sonication by bees, flowers likely cannot readily manipulate effectiveness in terms of pollen removal via these cues.

25-3 Mossor, AM*; Young, JW; Butcher, MT; NEOMED, Youngstown State University; *angela.mossor@yahoo.com*

Bone plasticity in arboreal mammals: Material and mechanical properties of sloth limb bones

Vertebrate bone is a conservative tissue, and compressive and tensile strength have been found to be generally similar across tetrapod taxa despite marked variation in limb posture and locomotor patterns. However, the material properties of limb bones from arboreal taxa have not been widely evaluated. Sloths are nearly obligatory in their use of below-branch suspensory locomotion and posture, which places their limb bones under routine tensile loading. It is possible that sloth limb bones have been modified for enhanced tensile strength while compromising some amount of compressive strength, a condition dissimilar to what is

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typical for upright (or crouched) terrestrial taxa. Long bones from the fore- and hindlimbs of two-toed (*C. hoffmanni*) and three-toed (*B. variegatus*) sloths were loaded in both axial compression and 3-point bending to test this hypothesis. Overall, compared to previously tested taxa, bone strength (60-120 MPa) and elasticity (1-9 GPa) were low under each loading regime with bone loading behavior displaying toughness over stiffness. A clear relationship could not be discerned between the elastic (Young's) modulus in bending versus compression, whereas both the humerus and femur from sloths showed a correlation between bending and compressive strength. These findings provide support for the hypothesis and infer some degree of elevated tensile strength that would match well with the predicted function of bone in a tensile limb system. Future studies aim to directly load bones in axial tension and observe the microstructure/material composition of sloth bones to verify potential modifications related to increases in tensile strength for suspensory habits.

108-2 Moyen, NE*; Crane, RL; Somero, GN; Denny, MW; Hopkins Marine Station, Department of Biology, Stanford University; *nmoyen@stanford.edu*

Rapid gain and slow loss of heat tolerance in Mytilus californianus reflects an adaptive response to timing of heat stress events in the field

Climate change is causing not only steady increases in average global temperatures but also an increasing frequency with which extreme heating events occur. These extreme events may be pivotal in determining the ability of organisms to persist in their current habitats. Thus, it is important to understand how the rate of gain and loss of heat tolerance by organisms compares with the frequency of extreme heating events in the field. We show that the California mussel, *Mytilus californianus* —a sessile intertidal species that experiences extreme temperature fluctuations and cannot behaviorally thermoregulate—can quickly (in 24–48 h) heat acclimate after exposure to a single sublethal heat-stress bout (2 h at 30 or 35° C) and can maintain this improved tolerance for up to ~3 weeks without further exposure to elevated temperatures. This adaptive response improved survival rates under extreme heat stress bouts (2 h at 40° C) by ~75%. To apply these lab findings in an ecological

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context, we evaluated 4 y of mussel body temperatures recorded in the field. The majority (~64%) of heat stress bouts are separated by 24-48 h, but were at times separated by as much as 22 days. Thus, the ability of *M. californianus* to maintain improved heat tolerance for up to 21 days after a single sublethal heat-stress bout significantly improves their probability of survival, as ~36% of consecutive heat events are separated by 3-22 days. We show that mussels have evolved a highly adaptive strategy to survive their habitat, whereby quickly gaining, and slowly losing, heat tolerance promotes survival. This strategy will likely allow mussels to survive the intermittent and extreme heat events predicted with climate change.

28-1 Mroue-Ruiz, FH*; Schramm-Urrutia, Y; Pacheco-Sandoval, A; Giffard-Mena, I; Abadía-Cardoso, A; Chong-Robles, J; Lago-Lestón, A; Universidad Autónoma de Baja California, Mexico, Centro de Investigación Científica y de Educación Superior de Ensenada, Mexico, Centro de Investigación Científica y de Educación Superior de Ensenada, Mexico; *mrouefadia@gmail.com*

Metabarcoding analysis of stomach contents in Totoaba macdonaldi

Totoaba macdonaldi is an endangered fish species endemic from the Gulf of California, and was a source of livelihood for people along the coast. Due to overexploitation, the Mexican government banned the fishery in 1975. However, it is still illegally fished and exported to China because the gas bladder is highly valued in traditional Chinese medicine. Despite its status, little is known about Totoaba biology. In order to optimize Totoaba farming, and to include the knowledge about its trophic ecology in conservation efforts, the diet of this fish has to be well characterized. Therefore, the aim of this study was to standardize a metabarcoding protocol to describe the diet by next-generation sequencing. We dissected four wild Totoaba individuals that had been seized by Mexican law enforcement agents, and we collected the stomach contents. From extracted DNA, we generated four representative amplicon libraries for cephalopods, chordates, marine invertebrates, and eukaryotes. After sequencing, we identified 12 different prey indicating Totoaba's preference for fish (9 species), mainly Pacific anchovy (*Cetengraulis mysticetus*) and Flathead grey mullet (*Mugil cephalus*). Other identified prey were

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members of the *Euphausiidae* family (krill). Compared with previous studies based on morphological recognition of prey in 35 stomachs, we identified more taxa and species (18 and 14 vs 15 and 3, respectively) in only 4 stomachs. Moreover, we found seven new prey species. Our work confirms that metabarcoding is an effective method to study the feeding habits of this species, providing the tools to further analyze Totoaba diet.

45-1 Muhammad, S*; Morag, MF; Welch, KC; University of Toronto; *saad.muhammad@mail.utoronto.ca*

Food for thought: What happens to fructose in the ruby-throated hummingbird?

Hummingbirds are nectivorous birds that can uniquely fuel energetically demanding hovering flight with either recently ingested glucose or fructose. Hummingbird flight muscles posses both glucose and fructose transporters, thus allowing for direct fructose oxidation. However, the rates of fructose phosphorylation via hexokinase are not enough to sustain hovering flight. Thus, the utilization of sugars, particularly fructose, are unclear in hummingbirds. To elucidate this, we first determined whether fructose was present in the blood. Using LC-MS based metabolomics on the plasma of sucrose (glucose and fructose) fed hummingbirds we determined that fed hummingbirds had a blood fructose level of 5mM, compared to 0.2mM in fasted individuals. Glucose values between the two conditions stayed similar suggesting that fructose levels are relatively more dynamic. To explore the possible differential uses of fructose and glucose at the major organs, we compared ruby-throated hummingbirds fed glucose or fructose to fasted hummingbirds. We focused on the concentrations of central carbon metabolism metabolites in liver, heart and pectoralis muscle of these birds. We found that the hummingbird can use native fructose in the aforementioned tissues. However, there was surprisingly almost no difference between glucose fed and fructose fed birds, particularly at the pectoralis muscle. We found strong evidence that this was because a large portion of fructose is converted into glucose in the liver and shunted to the heart and pectoralis muscle for oxidation. Thus, the ruby-throated hummingbird not only possesses a higher capacity to use native fructose compared to

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mammals, but also seems to posses an extremely high capacity to rapidly convert fructose to glucose.

61-5 Muir, CD*; Sheth, SN; Angert, AL; University of Hawai'i, North Carolina State University, University of British Columbia; *cdmuir@hawaii.edu*

How will climate change affect the variance in fitness? An empirical test in the perennial herb Mimulus cardinalis

George Gilchrist's fly lab at the College of William and Mary studied adaptation to climate on ecological time scales. Now a major question is whether evolution can rescue populations in demographic decline caused by rapid climate change. The answer depends in part on the variance in fitness, which determines the rate of adaptation. The variance is fitness is not necessarily static, but can increase or decrease depending on the rate of climate change and the niche breadth of organisms. These are empirical parameters that must be measured in the field. In this study, we used a space-for-time substitution with five populations of the perennial herb *Mimulus cardinalis* to measure how the mean and variance in fitness change as populations move farther from their climatic optimum. If the variance in fitness increases with climatic distance, a proxy for future climate change, then evolutionary rescue may be easier than predicted by models assuming constant variance. Conversely, if variance in fitness decreases with climatic distance, then evolutionary rescue should be less likely. This talk is dedicated in honor of Dr. G's contributions to undergraduate teaching and research.

34-2 Mullen, SC*; Knecht, KJ; Rees, BB; University of New Orleans; *brees@uno.edu*

Evaluating methods to determine maximum oxygen consumption by Gulf killifish, Fundulus grandis

Metabolic rate is an essential feature of animal physiology and ecology. The rate of aerobic metabolism, as determined by oxygen consumption rate (MO_2), is influenced by a variety of factors, including body size, temperature, and activity levels. Maximum aerobic metabolic rate (MMR) reflects the physiological capacity of an animal for oxygen extraction and utilization. As such, MMR is

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argued to be an important feature of an animal's life history. For fish, MMR is frequently estimated as the peak MO_2 immediately following an exhaustive chase, although several studies indicate that this value may underestimate MMR. Instead, MMR may be attained during sustained swimming or following ingestion of a large meal. In this study, we used intermittent-flow respirometry to quantify MO_2 by the Gulf killifish, *Fundulus grandis*, following 3 min chase or ingestion of a meal representing 5-15% of the fish's body mass. Peak post-prandial MO_2 was marginally higher than MO_2 after chasing. Interestingly, the highest MO_2 recorded in these trials was frequently after changes in light-dark cycle, rather than after either chasing or feeding. Current experiments evaluate MO_2 during sustained swimming. Taken together, our results suggest that MO_2 after an exhaustive chase may underestimate MMR in *F. grandis*, as reported for other fish species.

30-9 Munley, KM*; Dutta, S; Jasnow, AM; Demas, GE; Indiana University, Kent State University; *kmunley@indiana.edu*

Adrenal melatonin 1a receptor (Mel1aR) signaling regulates territorial aggression in male Siberian hamsters (Phodopus sungorus)

Many animals exhibit pronounced changes in physiology and behavior on a seasonal basis, and these adaptations have evolved to promote survival and reproductive fitness among conspecifics. While the neuroendocrine pathways mediating seasonal reproduction are generally well-studied, far less is known about the mechanisms underlying seasonal changes in social behavior, particularly outside of the context of the breeding season. Previous work from our lab suggests that seasonal shifts in secretion of the pineal hormone melatonin (MEL) are important in regulating territorial aggression in Siberian hamsters (*Phodopus sungorus*); it is unclear, however, how MEL signaling at the level of the receptor modulates this behavior. In this study, we infused a MEL 1a receptor (Mel1aR)-overexpressing or control lentivirus bilaterally into the adrenal glands of male Siberian hamsters. Animals were then housed in long-day (LD) or short-day (SD) photoperiods (characteristic of the breeding and non-breeding seasons, respectively) and administered timed MEL or control injections, and aggressive behavior was quantified following 10 weeks of treatment. LD males

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infused with Mel1aR-overexpressing lentivirus had significantly higher adrenal *Mel1aR* expression than LD control males, as determined via quantitative PCR. Furthermore, adrenal *Mel1aR* overexpression and timed MEL injections differentially affected body and relative reproductive mass in LD males. The potential relationship between adrenal *Mel1aR* expression and aggression will also be examined. Collectively, our findings provide insight into how MEL signaling via Mel1aR mediates aggressive behavior in seasonally breeding species.

BSP-2-9 Muñoz, MM; Yale University; *martha.munoz@yale.edu*
Gans Award Address: 'Constraint', a double-edged sword for evolution
One of the universal truths of evolution is that it occurs unequally across the tree of life: whereas some traits and lineages can remain inert (or nearly so) over millions of years, others appear to achieve evolutionary overdrive. My research centers around exploring the mechanisms underlying this phenomenon from single species to entire lineages. These explorations range from the evolutionary physiology of lizards and amphibians to the comparative biomechanics of fishes and stomatopods. Despite the different systems and approaches, an emergent theme from these inquiries is that 'constraint' serves as a dual-edged sword for evolutionary diversity. Behavioral constraint, for example, can result in both faster or slower evolution, depending on the ecological context. Mechanical constraint can enhance the rate of evolution, but the magnitude of this phenomenon varies across contexts. Evolution is a noisy process, but the dual role of "constraint" as both a motor and brake for diversity is a widespread signal.

61-1 Muñoz, MM; Yale University; *martha.munoz@yale.edu*
Welcome to the Special Session: An introduction
In this special session we honor the life and legacy of Dr. George Gilchrist. I will introduce the speakers and major themes of the session. I will also share a few thoughts about George and how he inspired my research and supported my scientific career.

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61-15 Muñoz, MM; Yale University; *jjsocha@vt.edu*
Group discussion and toast
Group discussion and toast to end the session in honor of Dr. George Gilchrist.

25-5 Munteanu, VD*; Diamond, KM; Blob, RW; Clemson University, Seattle Children's Research Institute; *munteanu.david@gmail.com*
Changes in limb bone neutral axis orientation during climbing in iguanas
Limb bone biomechanics are expected to reflect differences in the habitats and functional tasks that vertebrate species encounter. Measurements of bone strain can test how skeletal loads change among different habitats and behaviors. We evaluated changes in strain magnitudes between level walking and climbing in green iguanas, a lizard that frequently climbs trees. However, changes in loading may also include shifts in the orientation of the neutral axis through limb bone cross-sections, reflecting changes in the direction of bending. We used strain gauges implanted on the humerus and femur to evaluate changes in neutral axis orientation for iguanas between level and inclined (60 deg) surfaces. We predicted that, as the anatomical planes of the limbs reorient relative to gravity when animals climb, neutral axis orientation should rotate by an amount comparable to the incline of the slope. Our results did not bear out this prediction. For the humerus, we found little change in neutral axis orientation during steps in either substrate condition - the axis began the step oriented from anterior to posterior, and reoriented only slightly from anteroventral to posterodorsal. In contrast, femoral neutral axes began steps oriented from anteroventral to posterodorsal, but then shifted parallel to the ventral surface during steps, reflecting medial rotation of the limb. However, these patterns of change for the femur were maintained across different trackway conditions, and were largely similar to patterns observed previously in quadrupedal reptiles using sprawling posture (e.g. *Alligator*, *Tupinambis*). Results for both limbs thus suggest that arboreal habitats may not have strong effects on neutral axis orientation and bending direction of limb bones during locomotion.

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76-1 Murphy, KM*; Liles, MR; Higgins, KV; Mendonca, MT; Warner, DA; Auburn University, Auburn, AL; *kmm0155@auburn.edu*

Methodology for sampling the microbiome of lizard eggs

Most surfaces are colonized by microorganisms that form interactive and fluctuating communities, commonly referred to as the ‘microbiome.’ To effectively sample the microbiome, different methods are employed depending on the tissue or surface type. Although most vertebrates are oviparous, little is known about how microorganisms are represented on eggs, particularly those of non-avian reptiles. Using three different experiments, our primary goal was to develop methods to effectively sample and manipulate the eggshell microbiome of reptiles, as well as to minimize contamination from external sources. We employed two different egg microbiome sampling methods (sonication vs. swabbing) on lizard (*Anolis sagrei*) eggs and elucidated bacterial taxa using 16S rRNA gene-sequencing. We also assessed the efficacy of ethanol and bleach in reducing bacterial communities on the eggshell and their influence on egg survival. Lastly, to sample the maternally-derived eggshell microbiome (minimizing contamination from nesting substrate), we attempted to hormonally-induce oviposition in sterile conditions. We found that swabbing provided similar abundance and diversity measurements as sonication, but these sampling techniques differed in terms of bacterial community structure. Bacterial community load was reduced using 70% ethanol and 20% bleach. Additionally, ethanol greatly reduced egg survival while bleach did not. Lastly, we could not successfully induce oviposition in *A. sagrei* using previously described methods in the literature, thus future experiments that examine effects of different hormones on oviposition are warranted. Overall, our results provide useful guidelines for future studies that examine the source and function of the eggshell microbiome.

100-7 Murphy, D*; Garayev, K; Mee, T; University of South Florida; *davidmurphy@usf.edu*

The collective response of antarctic krill schools to various laboratory flow conditions

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Antarctic krill (*Euphausia superba*) are a key link in the Southern Ocean food web and form massive schools extending for several kilometers horizontally and for hundreds of meters vertically. These schools may increase swimming efficiency and enhance their collective ability to sense prey, predators, or conspecifics. However, the collective behavior of Antarctic krill schools in response to environmental cues such as flow, light, and predator and food odorant levels is not well understood. Working at Palmer Station, Antarctica, we used a novel annular flume capable of generating flow speeds on the order of 1-100 mm s^{-1} to investigate how various flow conditions affect krill schooling characteristics. The flume's inner and outer diameters were 0.3 m and 1.2 m, respectively, creating a 0.45 m wide and 0.13 m deep channel for the school. Flow was generated by rotating the inner cylinder and by submersible pumps positioned along the outer wall and was characterized after experiments using particle image velocimetry (PIV). In these experiments, 700 krill were placed in the tank at a density of 5 krill L^{-1} and were subjected to flow speeds of approximately 15 and 30 mm s^{-1}. Three-dimensional krill positions were measured by an overhead stereophotogrammetry system comprising three cameras filming at 23.7 Hz. Antarctic krill exhibited collective schooling behavior at both flow conditions as they swam against the flow. One minute of footage was processed for each flow condition, and krill swimming speed, school polarity, nearest neighbor distance, and nearest neighbor positions were analyzed. Krill at the higher flow condition swam at higher speeds and at slightly greater distances from their nearest neighbors.

93-7 Murphy, MJ*; Westerman, EL; University of Arkansas; *mjm052@uark.edu*

The effect of habitat on visual sensitivity across animal phyla

The spectrum of light that an animal can see - from ultraviolet to far red light - is governed by the number and wavelength sensitivity of a family of retinal proteins called opsins. It has been hypothesized that the spectrum of light available in an environment influences the range of colors that a species has evolved to see. However, invertebrates and vertebrates, which often live in similar habitats, use phylogenetically distinct groups of opsins in their retinae to see. It is unclear whether habitat

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similarly affects visual sensitivity across animal phyla, particularly when comparing across lineages that use different types of opsins. To close this gap in our knowledge, we conducted a systematic literature review that compared the bluest, reddest, and range of colors seen by >200 species of invertebrates and vertebrates to the habitats in which they live. We found that aquatic animals see bluer and redder light than terrestrial animals, and that invertebrates see bluer light than vertebrates; however, controlling for phylogeny removes the effects of habitat and lineage on visual sensitivity. We found that closed and open habitat terrestrial species have similar spectral sensitivities, but that deep water animals see bluer light than shallow water animals. These results suggest that, while ecological factors influence animals' visual sensitivities, evolutionary history a strong effect on which colors a species can see.

46-5 Murphy, TE*; Rees, BB; University of New Orleans; *brees@uno.edu*

The effect of short-term hypoxia on HIF mRNA levels in Fundulus grandis

Low dissolved oxygen, hypoxia, is a prevalent stressor in aquatic environments arising from natural and anthropogenic events. Included in the biological responses to hypoxia are changes in gene expression that are coordinated by the hypoxia-inducible factor (HIF) family of transcription factors. The paradigm for HIF signaling is that alpha subunits (HIFα) are degraded during normoxia, but degradation is suppressed at low oxygen, leading to the accumulation of HIFα, dimerization with beta subunits, and regulation of target gene transcription. In fish, there is evidence that HIF1α mRNA levels also increase during hypoxia, but these measurements are from experiments without corresponding protein levels. Therefore, in this study, we addressed two questions. Do levels of HIFα mRNA increase after short-term hypoxic exposure? Do levels of HIFα mRNA correlate with protein levels measured in the same tissues? *Fundulus grandis*, a small, abundant, estuarine fish, was exposed to approximately 1 mg/l O_2 for 6 or 24 h, after which RNA was extracted from liver, gills, ovary, and skeletal muscle. HIF1α mRNA levels were determined by quantitative PCR. The results show that there were no changes in HIF1α mRNA under these

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conditions, even when HIF1α protein levels were significantly elevated. Our results support a role for protein stabilization, rather than new transcription in the initial response of fish to low oxygen, in agreement with the paradigm developed for HIF signaling in mammalian cells.

88-5 Muzzatti, MJ*; MacMillan, HA; Bertram, SM; Carleton University, Biology Department, Ottawa, ON; *mattmuzzatti@cmail.carleton.ca*
Farming fecund crickets: fruitful female fertility from feeding crickets royal jelly
Insects are a sustainable and nutritious alternative protein source, and crickets are an economically important insect in the North American entomophagy industry. A primary goal of agricultural research is to increase yield. Increased body size in cricket farms is desired, but we have little knowledge on how to do it at such a large scale. Diet supplementation using honey bee royal jelly is a potential solution, as there is evidence that royal jelly enhances body size of other insect species including one orthopteran. The mechanisms behind how royal jelly does this remain unclear. To determine the effect of royal jelly on a farmed cricket species, 96 *Gryllodes sigillatus* were obtained from a local Canadian cricket farm, individually housed, and split into two treatment groups: half were reared on a commercially available cricket diet, while the other half were reared on the same diet mixed with 15% w/w fresh royal jelly. Body size and mass measurements were taken weekly for six weeks (approximate time to adulthood). We discovered a female-only effect of royal jelly on *G. sigillatus*: females fed the royal jelly diet grew to be 21% heavier, and this effect was driven by significantly longer abdomens containing 66% more eggs each compared to those fed the basal diet. We are now replicating this experiment in a simulated farm environment to determine whether increased female fertility from royal jelly persists in high-density rearing environments like an active commercial farm.

30-8 Myers, DC*; Davis, JE; Radford University; *dmyers27@radford.edu*
Thinking hard: Measuring physiological and neuroendocrine

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responses to problem-solving challenges in a captive avian social system

Problem solving tasks aren't a purely human experience. Intelligent, non-human species must also learn and change based on new challenges in their environment. Previous research has shown that avian species are able to adapt and solve simple tasks placed before them. We also have substantial insight into how these species react to stressors in their environment. This study explores the impact of intellectually demanding tasks on stress responses and the potentially moderating impact of social factors on both task performance and stress indices. In this study, captive zebra finches (*Taeniopygia guttata*), a highly social and intelligent species, were subject to a challenge placed in their environment. This challenge included a barrier that had to be maneuvered around to obtain food, which deviated from the normal way feed is accessed. Hormone testing was completed along with behavioral analysis to contrast responses among varying social settings. We hypothesized that problem-solving tasks would induce a stress response and result in a reallocation of energy away from other biological activities (reproduction, self-repair, etc.), as measured through corticosterone, testosterone, and osteocalcin levels. We also believe that task performance will stay the same for individuals but vary across sex and social rank, and that this performance will decrease, and stress levels increase when the opportunity for social learning is taken away. This research may clarify basic features of social organization and intellectual processing, as well as hold implications for the evolution of intelligence and sociality.

26-8 Myrka, AM*; Frost, R; Distefano, D; Plotnikov, SV; Buck, LT; University of Toronto, Cell and Systems Biology, Toronto, Ontario; *alex.myrka@mail.utoronto.ca*

Cold stimulated cytoskeletal arrest in western painted turtle hepatocytes

The western painted turtle *Chrysemys picta bellii* can survive without oxygen (anoxia) for months while overwintering, during which time metabolic rate must be decreased so that ATP demand does not exceed anoxic ATP supply. In order to understand how metabolic depression is achieved in non-excitable turtle cells, we have

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optimized a hepatocyte cell culture system. We are approaching control of hepatocyte metabolic depression from multiple intersecting avenues, including mitochondrial signaling, actin and tubulin cycling, and mitochondrial dynamics. Actin and tubulin cycling are large consumers of cellular ATP pools, and we hypothesized that their cycling activity would be downregulated by overwintering conditions. We observed inhibition of cytoskeletal dynamics at overwintering temperature (4° C), signaling that is not induced by acute administration of either cyanide or oxygen tensions down to 0.1 Torr. A lesser response was observed with chronic exposure to cyanide. Acute decrease in temperature caused inhibition of actin polymerization, while cortical actin partially depolymerized. Hepatocytes plated at 4° C failed to reorganize the actin and tubulin cytoskeleton and mitochondrial density was low. Acute or chronic low temperature, or chronic cyanide exposure, resulted in reduced 2D cellular surface area. Increase in cytosolic calcium and associated mitochondrial depolarization appear key to actin cycling arrest.

56-5 Najar, N*; Fernandez, L; Clark, C; University of California, Riverside, University of Aberdeen and University of California, Riverside; *nnaja003@ucr.edu*

Hummingbird load lifting performance not predicted by top speed in a wind tunnel

Hummingbirds are capable of flight over a wide range of flight speeds, from hovering to rapid forward flight. The load lifting assay tests the maximum amount of weight a bird can lift. This assay has been widely used because it requires simple, field-portable equipment. However, it represents flight performance at low flight speeds. Here we ask: is performance of low-speed and high-speed flight correlated? We tested this by flying 50 wild hummingbirds of four species (*Calypte anna*, *Calypte costae*, *Selasphorus sasin*, and *Archilochus alexandrei*) in the load-lifting assay as well as measuring their top speed in a wind tunnel. As these species are all sexually dimorphic, and the species also vary in body size and wing loading, we used path analysis to ask: what determines the maximum forward flight speed of a bird? The best-supported path model suggested wing length and keel size (a proxy for flight muscle mass) best predicts load

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lifting performance, while wingtip velocity (proportional to wing length multiplied by stroke amplitude and wingbeat frequency) and keel size predicts top speed. However, load lifting ability and top speed are not correlated and do not covary, despite both being partially predicted by keel size. These results suggest lifting extra mass vertically and fast forward flight are limited by different morphological traits and are fundamentally different processes.

63-8 Names, G*; Schultz, E; Klasing, K; Univ. of California, Davis, Wittenberg Univ.; *grnames@ucdavis.edu*

Immunological and health correlates of avian malaria infection and resilience in the Hawaii Amakihi (Hemignathus virens)

Infectious diseases are emerging and spreading at unprecedented rates, affecting wildlife worldwide. Since the introduction of avian malaria to Hawaii a century ago, the disease has contributed to the decline and extinction of several endemic Hawaiian honeycreeper species. Evidence suggests that populations of one honeycreeper species, the Hawaii Amakihi (*Hemignathus virens*), that have experienced strong selection by avian malaria have evolved resilience to the disease. However, the mechanisms of avian malaria resilience, as well as the consequences of resilience and chronic infection on bird health, remain poorly understood. The goals of this study were to examine the role of innate immunity in malaria resilience and determine the effects of resilience and chronic infection on Amakihi health. To do so, we measured the innate immunity and health of infected and uninfected free-living Amakihi from low elevation populations, which have experienced strong election by avian malaria, and high elevation populations, which have experienced weak selection by the disease. As expected, measures of innate immunity were higher in low than high elevation Amakihi, although these relationships were dependent on environmental context. Regarding measures of health, results were mixed. Body condition was higher in high than low elevation birds, but only on the leeward side of the island, and higher in malaria infected than uninfected Amakihi. Hematocrit was higher in high than low elevation individuals but, surprisingly, did not vary by malaria infection status. These are among the first results to describe phenotypic differences related to the immune function and

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health of Amakihi varying in avian malaria resilience and infection.

BSP-4-6 Nanes Sarfati, D*; Xue, Y; Byrne, AL; Le, D; Darmanis, S; Sikes, J; Wang, B; Stanford University, CA, Chan Zuckerberg Biohub, San Francisco, CA, Chan Zuckerberg Biohub, San Francisco, CA, University of San Francisco, CA; *danians@stanford.edu*

The acoel Convolutrilba longifissura fuels up for regeneration through its algal symbionts

Symbiotic mutualistic associations prevail in nature, but how organisms overcome stress while maintaining symbiotic relationships is poorly understood. The marine acoel *C. longifissura* hosts a large population of obligate extracellular endosymbiotic green algae. This acoel is able to regenerate all missing body parts from small tissue fragments, while the algae repopulate the newly formed tissue. To understand how these two organisms coordinate their responses to injury and cooperate during tissue regeneration, we used nanopore long-read RNA sequencing to measure transcriptomic changes in both organisms during early stages of acoel regeneration. While the acoel wound response appeared to be highly conserved and driven by a homolog of *early growth response* transcription factor, the algae upregulated metabolic pathways associated with photosynthesis. Chemically blocking photosynthesis did not change the rate of acoel regeneration, but quickly reduced the algal density. In contrast, under homeostatic conditions, photosynthesis inhibition did not cause a similar reduction in the algal population. Since acoels are capable of ingesting algae, our results suggest that consumption of the symbiotic algae may be a strategy to satisfy the higher metabolic demands during acoel regeneration. A compensatory increase in photosynthesis, and thereby algal proliferation, are required to support acoel regeneration and maintain the symbiotic relationship during this stress condition.

94-11 Natesan, D*; Dave, SD; Saxena, N; Sane, SP; National Centre for Biological Sciences, Bangalore and KTH Royal Institute of Technology, Stockhol,, Case Western Reserve University, Cleveland, Ohio, National Centre for Biological Sciences, Bangalore, National

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Centre for Biological Sciences, Bangalore; *dinesh@ncbs.res.in*
Flexibility of reflexes: How Johnston's organs modulate the antennal set-point in flying hawkmoths
The positioning of antennae in insects involves aspects of both stability and flexibility. On short timescales, rapid proprioceptive feedback about the position of the antennae is used to keep them stable at a preferred position, hereafter referred to as the set-point. On longer timescales, this set-point is flexibly modulated by sensory inputs from multiple modalities including vision and airflow. Whereas the antennal stabilization reflex has been investigated using control theoretic techniques and neural circuit models, the mechanisms that underlie modulation of antennal set-point are not well understood. In the current study, we investigate the modulation of antennal set-point using the airflow-dependent antennal positioning behavior in the Oleander hawkmoth, *Daphnis nerii*. Our previous work has shown that airflow-dependent control of antennal position requires sensory inputs from the Johnston's organ (JO), an antennal mechanosensory organ that senses vibrations of the antennae. Here, using behavioral experiments, we investigate the role of individual JOs in modulating the set-point of both antennae. We find that unilateral restriction of JOs disrupts the set-points of both antennae for different airflows. To further characterize this, we used a finely calibrated stimulus setup to deliver precise flagellar vibrations to the antennae while simultaneously recording from the extrinsic muscles of both antennae. By pooling behavioral and electrophysiological data, we aim to characterize how the sensory inputs from the JOs tune the antennal set-point and modulate antennal positioning.

S4-14 Nation, JM*; Hansen, AK; California Polytechnic State University, San Luis Obispo, California State University, Fresno; *jmnation@calpoly.edu*
Students' experiences in community STEM programs
Given our rapidly changing world and the pressing challenges of climate change and health care, it is more important than ever for youth and the broader public to learn scientific knowledge and skills. To reach the most people possible and increase diversity in STEM fields, we need compelling educational approaches that

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incorporate the lived experiences of students. Partnerships between researchers, scientists, educators, and community groups can enrich and extend scientists' research while providing authentic scientific learning experiences for K-12 students, especially from STEM-underrepresented groups. However, more research is needed on equitable long-term partnerships, including how these projects are organized and how partners align their interests and goals. In this paper, we present findings from university-community partnership projects that utilize a Community STEM Framework, an approach which draws from individual and collective strengths, contextualizes science learning, and positions youth as producers of content and artifacts. To situate this work, we review and highlight biology-related citizen/community science projects and maker/engineering projects designed for youth. We characterize projects according to their goals and format, then examine students' experiences and the impact on youth in various Community STEM projects. A design-based research (DBR) approach was used to collect and analyze data on three Community STEM projects. The research followed DBR's dual goals of informing local practice and providing insight into complex issues, producing a model of learning and innovation that applies on a broader scale. Engagement in program design was flexible, ongoing, and co-designed with researchers and practitioners. Given DBR's focus on informing practice, we conclude with recommendations for this type of partnership in various biology contexts.

7-5 Naughton, LF*; Kruppert , S; Jackson, B; Porter , ME; Donatelli, CM; Bucknell University, University of Washington Friday Harbor Labs, Idaho State University, Florida Atlantic University , University of Ottawa; *Lfn001@bucknell.edu*

A Tail of Four Fishes: An analysis of kinematics and material properties of elongate fishes

The elongate body plan is present in many groups of fishes, and this morphology dictates functional consequences seen in swimming behavior. Previous work has shown that increasing the number of vertebrae in artificial systems increases stiffness and mean swimming speed. This demonstrates the impacts of morphology on both material properties and kinematics, establishing mechanisms for form contributing to function. However, we wanted to investigate

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relationships between form and ecological function, which manifested as differences in dietary strategies between fish species. This study aims to characterize and compare the kinematics, material properties, and morphology of four species of elongate fishes: *Anoplarchus insignis*, *Anoplarchus purpurescens*, *Xiphister atropurpureus*, and *Xiphister mucosus*. We hypothesized that the combination of these properties could distinguish the species from each other. To calculate kinematic variables, we filmed these fishes swimming of their own volition. We also measured body stiffness by bending sacrificed individuals in different stages of dissection (whole body, removed skin, removed muscle). Finally, we counted the number of vertebrae from CT scans of each species to quantify vertebral morphology. The results from the principal components analysis suggested that the elongate fish species can be distinguished from one another by their material properties, morphology, and swimming kinematics. With this information combined, we were able to draw connections between the physical properties of the fishes and their dietary ecologies since the only herbivore, X. mucosus, was dramatically separated from the other species.

33-5 Naugle, M*; Grossman, J; Logan, C; California State University, Monterey Bay; *nauglems@yahoo.com*
Effects of land-based sources of pollution on coral thermotolerance
Coral reefs are declining worldwide due to a combination of global and local stressors. Multiple stressors can have synergistic (increased stress) or antagonistic effects (decreased stress). For example, nutrient pollution and thermal stress have been shown to produce synergistic effects in corals, exacerbating the physiological damage. Conversely, mild heat stress has been shown to prepare corals to better cope with the same or other types of environmental stress. To examine the interaction between land-based sources of pollution and thermal stress, acute heat stress experiments were conducted on *Acropora hyacinthus* from five sites around Tutuila, American Samoa with differing pollution impact. Bleaching responses were measured visually, using photographic assessment to estimate chlorophyll content, and through measuring photosynthetic efficiency. Endosymbiont communities were assessed

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at each site using quantitative PCR. RNA sequencing was used to compare differences among genes regulated during heat stress. Preliminary results show differences in symbiont communities among sites, with heat tolerant *Durusdinium* dominating in areas with higher pollution impact and heat sensitive *Cladocopium* more common in pristine areas. Pollution stress may induce a shift towards *Durusdinium* thereby enhancing resistance to subsequent heat stress in the near term. RNAseq data showed more differentially expressed genes during heat stress in the high pollution site, with fewer differentially expressed genes in the medium pollution site and fewest in the low pollution site. We present potential mechanisms underlying coral thermal tolerance in pollution-impacted areas. Our results highlight the importance of identifying heat tolerant corals in "non-pristine" areas and their potential to seed nearby reefs following bleaching events.

73-8 Naylor, ER*; Higham, TE; University of California, Riverside; *emily.naylor@email.ucr.edu*

Frequent encounters of the compliant kind: the cursorial Namib day gecko maintains speed and alters posture during substrate transitions

Animal movement is often largely determined by abiotic conditions of the surrounding environment. While a large body of work has improved our understanding of how different substrate properties can impact locomotor performance, mechanics, and behavior, fewer studies have considered substrate transitions, or changes in substrate level, incline, texture, and/or compliance during a single locomotor event. Such transitions are common for animals in nature and can be particularly abrupt for high-speed animals. We investigated the occurrence and impacts of substrate compliance transitions in *Rhoptropus afer*, a cursorial day gecko known for its ability to sprint rapidly for several meters at a time. In addition to collecting video recordings of substrate use during escapes in the field, we conducted locomotor trials on a level trackway featuring a transition from a solid surface into and out of sand. We found that *R. afer* uses substrates of different compliance and transitions to and from more compliant surfaces fairly equally in the wild. Moreover, laboratory trials revealed that this species is able to maintain forward velocity during sand transitions but

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exhibits increased body angle and duty factor upon entering sand; this may represent active and/or passive kinematic responses to acute changes in compliance. This study provides important insight as to how geckos and other animals accommodate natural, often heterogeneous, substrate conditions during critical high-speed locomotor events, such as predator evasion.

31-3 Nazarian, LA*; Bukovich, IMG; Currylow, AF; Josimovich, JJ; Robinson, CJ; Nafus, MG; Yackel Adams, AA; Parker, MR; James Madison University, Harrisonburg, VA, USGS Ft. Collins Science Center, CO, USGS Ft. Collins Science Center, CO; *nazarila@dukes.jmu.edu*

Testing the role of hormone-driven chemical signals in Burmese python trailing behavior

Reptiles use chemical signals from their environment to inform crucial behavioral processes, such as hunting prey or searching for mates. Previous studies found that male Burmese pythons (*Python bivittatus*), a major invasive predator in the Florida Everglades, can distinguish between scent trails laid by conspecifics and follow female trails. To further test this idea, we have collaborated with the National Park Service to assess the role of estrogens in activating female chemical signal production in pythons. The ultimate goal is to determine if pheromone development is a tractable management target. Male pythons were implanted with silastic implants containing either estradiol (E2; n=6) or left blank (SHAM; n=6). Wild, opportunistically caught male pythons (n=39) were then tested in a Y-maze to determine if they could follow either scent trail when left by an experimental animal in the maze. Many behaviors were observed during the trials (i.e., head shakes, pauses, turns, head raises). While the array of behaviors across the full trial (~12 hours) provides more insight on the patterns of wild male python behavior, those behaviors exhibited just until arm choice was made were prioritized for analysis. If wild males demonstrate more frequent behavior(s) toward E2 scent compared to SHAM scent, chemical feminization may have occurred which will be biochemically validated. The main outcome is the development an effective pheromone lure to enhance performance of trapping and removal efforts in South Florida.

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37-1 Nedved, BT*; Freckelton, MF; Hadfield, MG; University of Hawaii at Manoa / Kewalo Marine Laboratory; *nedved@hawaii.edu*

Bacterial induced metamorphosis: holes in excitable membranes?

Most benthic marine invertebrates begin life with a mobile larval phase that must undergo metamorphosis to obtain the adult form. For many (non-arthropod) invertebrates this process involves an external stimulant that induces an extremely rapid neurogenic sequence of events. For the cosmopolitan marine worm *Hydroides elegans* the external cue originates with certain biofilm bacteria. One such bacterium, *Pseudoalteromonas luteoviolacea*, induces metamorphosis in larvae of *H. elegans* with complex clusters of organelles known as tailocins. Tailocins have been demonstrated to kill other bacteria by puncturing their cell membrane and causing a lethal ion flux. We hypothesize a similar mechanism for induction of metamorphosis: that puncturing the membrane of a sensory cell is sufficient to stimulate metamorphosis. To test this hypothesis, we aimed to (1) chemically create holes in membranes larvae of *H. elegans* with saponins and (2) inhibit metamorphosis in larvae of *H. elegans* with low sodium artificial seawater. Low sodium artificial seawater should inhibit the formation of action potentials across excitatory membranes and prevent larvae from responding to inductive cues. Using 1 h pulse exposures, larvae were subjected to both natural and artificial cues in the presence of low sodium artificial seawater and then allowed to recover in sterile seawater. We found that metamorphosis was significantly reduced in the presence of low sodium seawater, suggesting that the generation of action potentials play an important role in the induction of metamorphosis in the larvae of *H. elegans*.

59-3 Neel, LK*; Fornshell, D; Angilletta, MJ; Arizona State University; *lkneel@asu.edu*

The effects of predicted activity time on population-level measures of productivity in squamates: a comparative analysis

Ectotherm performance is highest within a relatively narrow range of body temperatures. As climates warm, organisms are expected to achieve their preferred body temperatures less frequently, constraining the time available for foraging, mate acquisition,

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territory defense, and thermoregulation. To understand how climate change will impact the persistence of ectotherms, it is important to understand how thermal constraints on activity impact the productivity of ectotherms in different environments However, the costs of restricted activity on population-level measures of productivity are difficult to quantify for myriad reasons. Here, we searched primary literature for studies that quantified any of three measures of productivity: 1) growth rates, 2) relative clutch mass, or 3) reproductive output. Data for relative clutch mass and reproductive output (mean ± se) were taken directly from the publications, while growth rate data were collected from growth trajectory figures using the freeware, WebPlotDigitizer. Then, we integrated estimates of heat flux from complex environments using the approach developed by Campbell and Norman (1988) and Bakken (1980), with downscaled microclimate data from NicheMapR, to model hourly body temperatures throughout the year for each population sampled. We use preferred temperatures to predict activity restrictions. We compare predicted annual activity times to population-level measures of growth and reproduction using computation modeling and pre-existing productivity data from n = 58 lizard species across n = 126 studies. Future work will incorporate phylogenetic relationships into our statistical models.

S2-1 Neiman, M*; Matoo, O; University of Iowa, University of Nebraska; *maurine-neiman@uiowa.edu*

Introduction to genomic perspectives in comparative physiology of mollusks: Integration across disciplines

Characterizing the genetic pathways that affect ecological success and evolutionary fitness in natural environments and populations in increasingly important in the face of global climate change. Connecting genotypes and genomic variation to functional and ecological consequences demands tools and concepts from a diverse set of fields including molecular biology, physiology, quantitative genetics, ecology, and evolutionary biology. This type of integrated approach will help to identify and decouple genetic vs. plastic underpinnings of ecologically relevant functional variation and characterize the ecological consequences of that variation. Achieving this ambitious goal will require collaboration across disciplines as well openness to learning new concepts,

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methodologies, and tools. This symposium is designed to address these challenges both with respect to and with the example of mollusks, with the specific aim of integrating genomics data with the ecophysiology of mollusks. We will provide an interdisciplinary platform for scientists to present and discuss recent research bridging the gap between these two communities for a comprehensive understanding of mollusk biology. Our goal is to bring together experts in these two disciplines of mollusk biology to provide an unprecedented opportunity for knowledge exchange, discussion, and catalysis of new partnerships. The talks our symposium will feature will focus on a wide range of ecologically important concepts and traits including but not limited to immune function to symbiosis, mitochondrial performance, and host-parasite interactions, and will be united by their use or application of genomic techniques and resources.

S1-9 Nelson, RJ; West Virginia University; *randy.nelson@hsc.wvu.edu*
Effects of light at night and disrupted circadian rhythms on brain and behavior
Life on earth has evolved during the past several billion years under relatively bright days and dark night conditions. Virtually, all organisms on the planet display an internal representation of our rotating planet in the form of circadian rhythms. Among vertebrates, virtually every aspect of physiology and behavior, including metabolism, food intake, hormone secretion, body temperature regulation, mood, and sleep is mediated by these internal clocks. The widespread adoption of electric lights during the past century exposed animals, including humans, to significant light at night for the first time in their evolutionary history. Importantly, endogenous circadian clocks depend on light, especially short wavelength (i.e., blue) light, to entrain to the external daily solar environment. Thus, exposure to blue light at night can derange temporal adaptations. Indeed, disruption of natural light-dark cycles results in several physiological and behavioral changes with potentially serious implications for physiology, behavior, and fitness. In this talk, data from our lab will be reviewed on the role of dim light at night on metabolism and immune responses in rodents. The association among light at

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night, dysregulation of clock gene expression, and neuroinflammation will be presented.

18-4 Nguyen, C*; Ozkan-Aydin, Y; Bhamla, MS; Peleg, O; University of Colorado Boulder, Georgia Institute of Technology, University of Colorado Boulder and Santa Fe Institute; *chantal.nguyen@colorado.edu*

Modeling collective dynamics of aquatic worm blobs

Many organisms aggregate for the purposes of survival, forming collectives in which interactions between individuals give rise to emergent macroscale dynamics. Aquatic worms, for example, aggregate into an entangled blob to shield themselves against external stressors and preserve moisture in dry conditions. Motivated by recent experiments, we investigate the blob dynamics by modeling each worm as a self-propelled Brownian polymer. These simulations allow us to track the behavior of individual worms in order to uncover the mechanisms driving phase separation and emergent locomotion. We demonstrate how a blob is able to collectively traverse temperature gradients via the coupling between the active motion and the environment.

59-6 Nielsen, ME*; Lehmann, P; Gotthard, K; Stockholm University, Stockholm; *matthew.nielsen@zoologi.su.se*

Consequences of pre-winter temperatures for diapausing pupae

Diapause is considered an important adaptation for survival of adverse winter conditions; however, insects often enter diapause long before the onset of winter. Thus, diapausing insects must also be able to survive these warm conditions which can be quite metabolically taxing despite relative inactivity. We sought to test the consequences of the pre-winter warm conditions of varying temperatures and lengths on diapausing pupae of *Pieris napi*. After raising pupae into diapause, we placed them at one of three temperatures (15, 20, 25 ° C) for anywhere from 1 to 16 weeks, followed by the same duration of winter conditions for all individuals. We measured weight at multiple points during the experiment and whether individuals survived the entire period to emerge as healthy adults. For a subset of individuals, we also made repeated metabolic measurements. Initial results suggest that pre-

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winter temperature had a substantial effect on the rate of pre-winter weight loss, while only the duration of the pre-winter period clearly affected survival. Upcoming analysis of the post-winter mass and survival insight into the longer-term impacts of pre-winter conditions on life history. The ability to tolerate extended warm periods during diapause is particularly important for understanding selection on voltinism, particularly as climate change makes these pre-diapause warm conditions longer and more intense.

4-5 Nirody, JA*; Duran Rosario, LA; Johnston, D; Cohen, DJ; The Rockefeller University and University of Oxford, Princeton University; *jasmine.nirody@all-souls.ox.ac.uk*

Tardigrade stepping pattern is robust to changes in orientation and substrate

Limnoterrestrial tardigrades live and move through complex environments and may face large changes in substrate deformability and surface friction. How organisms control their movements during natural locomotion through uneven or variable terrain is not fully understood; in particular, very little is known about such mechanisms in soft organisms. Despite living in aquatic environments, tardigrades are poor swimmers; they are found primarily on or within the substrate and are among the smallest known walking animals. We analyze the kinematics of freely walking tardigrades (species: *Hypsibius dujardini*) on substrates of varying stiffness and at different orientations (i.e., on a flat surface and at a 90-degree incline). We find that the stepping pattern of the posterior-most leg pair shows high variability and does not strongly affect walking speed. However, the anterior three leg pairs display, and rarely deviate from, a regular tetrapodal gait analogous to that observed in insects. Despite disparities in size and skeletal and neuronal structure, tardigrades and stick insects both display flat-terrain walking patterns that are well described by the same inter-leg coordination 'rules'. Further, we find that, in tardigrades, this stepping pattern is robust to changes in both orientation and substrate stiffness. These results have implications for understanding the mechanisms -- neural and/or mechanical -- underlying coordination during invertebrate locomotion.

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S8-3 Noel, AC; Georgia Tech Research Institute; *alexis.noel@gtri.gatech.edu*

Characterizing frog tongue stickiness and other reversible adhesive mechanisms

Biological organisms have evolved unique reversible adhesion mechanisms to grip onto challenging substrates. Frogs and toads use a soft, porous tongue infused with viscoelastic saliva to capture slimy, dusty, or feathery prey. Octopuses, clingfish, and remora fish combine suction cups with micro-papillae or thick mucus to reduce leakage across the seal and grip onto slippery and scaly substrates. Reversible adhesion in biology is often a collaboration between soft tissues and fluid adhesives, leading to grip solutions that can easily adapt to unpredictable environments. We seek to characterize these robust biological adhesive mechanisms using morphological characterization, modeling and simulation, and experimental validation. Thick bio-fluids like frog saliva are characterized using a combination of shear and elongation rheology. We explore the potential of measuring bio-fluids on-site with a custom, portable rheometer that reduces the critical time between sample collection and testing. The role of tissue softness in adhesion is measured using micro-indentation pull-off techniques. For reversible underwater adhesion, we develop a modular apparatus that can test the longevity and strength of underwater grippers with variations in substrate and environmental conditions. Using a system of cameras, and force, pressure, and flow rate sensors, we identify and characterize failure criteria for grippers that utilize suction adhesion. By understanding how these reversible adhesive mechanisms grip onto challenging substrates, we look to address today's challenging grip problems through development of versatile and resilient artificial grippers.

57-4 Noonan, KR*; Childress, MJ; Clemson University; *noonan2@g.clemson.edu*

Butterflyfish effect: The relationship and influence of foureye butterflyfish on corals infected with stony coral tissue loss disease

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Within the past six years, a new pathogen, Stony Coral Tissue Loss Disease (SCTLD), has spread rapidly across the Florida reef tract causing widespread mortality for dozens of coral species. Although there is great interest in learning about the origin and pathology of this disease, there is less known about its relationship with reef fish communities, in particular coral-associated species like butterflyfish. This study investigates the abundance, habitat association, and foraging behaviors of butterflyfishes in the middle Florida Keys (USA) using field foraging studies. Diver visual surveys of butterflyfish abundance, foraging behavior, and disease prevalence were conducted across 10 reefs in the middle Florida Keys. An additional sample of 60 coral colonies of four species (MCAV, OFAV, CNAT, SSID) either recently dead, actively infected with SCTLD, or healthy were monitored for fish activity using time-lapse videophotography. Foureye butterflyfish were significantly more abundant than the three other species of butterflyfishes and were found in higher proportions at diseased coral colonies than at healthy or recently dead coral colonies. Furthermore, only foureye butterflyfish preferred to feed on infected coral colonies over dead or healthy corals and were observed to feed directly on the disease line where tissue loss was occurring. There were significantly different foraging patterns for individual versus paired foureye butterflyfish in our field study with individual fish feeding on hard coral whereas paired butterflyfish fed on more soft corals.

BSP-7-3 Notar, JC*; Meja, B; Johnsen, S; Duke University, Durham, NC; *julia.notar@duke.edu*

A living shag rug: Sea urchin spine density differs by habitat and has consequences for vision

Sea urchins are present in every major marine habitat worldwide, making them an ideal group to use in comparative studies. Here, we look at the relative impacts of habitat variation and phylogenetic relatedness on the density of spines on sea urchins. Spines may be used for defense, locomotion, and a variety of other behaviors, but they may also play a role in the unusual vison of urchins. Behavioral data show that urchins have spatial vision, with spatial acuities (measured in angular resolution) ranging from 10-33°, depending on the species. Acuities measured via behavioral assay

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match closely with the angular distance of spines across the body, and it has been suggested that the spines screen off-axis light and restrict the "view" of the patch of photosensitive skin between the spines. Essentially, the animal may function like a large, compound eye. In order to investigate the role of habitat and phylogenetic constraint on spine density and vision, we measured multiple individuals from 33 urchin species, representing every family of regular urchins within the order Echinoidea. We determined the density of spines around the equator of the animal, since this is the region of the body that views the horizon. We measured spine density by analyzing images of museum and other collected specimens and converted spine density measurements into angular resolutions. While we found little evidence of a phylogenetic signal in the trait, it does appear that spine density is more variable in deep, dark habitats than well-lit ones. This suggests that spine density may be subject to specific ecological pressures in well-lit environments (wave action, active predation, etc.) which can have a downstream effect on the visual acuity of the species.

96-2 Nowicki, S*; Caves, EM; Green, PA; Zipple, MN; Bharath, D; Peters, S; Johnsen, S; Duke University, Durham, NC, University of Exeter, United Kingdom, Indian Institute of Science, Bangaluru, India; *snowicki@duke.edu*

Differences in categorical color perception between two estrildid finches

Prior work has shown that the orange-red coloration of male zebra finch beaks, which is a carotenoid-based signal used in mate choice, is perceived by females categorically (i.e., either as "orange" or "red"), not in a continuous fashion. The Bengalese finch, an estrildid related to the zebra finch, is black, brown and white, and lacks carotenoid coloration. To explore the relationship between categorical color perception and signal use, we tested Bengalese finches using the same orange-red continuum as was tested in zebra finches. Bengalese finches did not exhibit categorical perception; instead, differences in brightness appeared to better predict discrimination ability. We further tested both species with colors that differed systematically in both hue (i.e., chromatic distance) and brightness (i.e., Michaelson contrast). Chromatic distance and brightness contrast correlated with color

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discrimination ability in Bengalese finches, while in zebra finches this correlation held only for between-category discrimination, not for within-category discrimination. These results suggest that categorical perception is not a general feature of avian visual systems and supports the possibility that this perceptual mechanism is adapted for signal function.

82-12 Nowicki, JP*; Sailer, LS; Ophir, AG; Gardner, MG; Coker, DC; O'Connell, LA; Stanford University, Cornell University, Flinders University, King Abdullah University of Science and Technology; *jnowicki@stanford.edu*

Neural correlates of vertebrate affiliative evolution

Animals display remarkable diversity in sociality, provoking fundamental questions about how it has evolved. Although variation in affiliative behavior, such as pair bonded versus solitary living, has independently evolved numerous times across vertebrates, little is known about the underlying neural mechanisms, or how they differ across species or lineages. Using immunohistochemical detection of phosphorylated ribosomes (pS6) as a proxy for neural induction, we are comparing brain region correlates of affiliative variation (pair bonded vs. solitary living) within and across species of five major vertebrate lineages: fishes, amphibians, reptiles, birds, and rodents. We will present our preliminary findings in the earlier lineages, while work on birds and rodents is still ongoing. We expect that a core subset of socially relevant brain regions will be repeatedly linked to social variation across vertebrates, while other brain regions associated with affiliative variation will be species- and lineage-specific. Our findings will be the first to reveal major neuroanatomical themes of affiliative diversity across vertebrates, shedding light onto how it has evolved.

102-5 Nyakatura, JA*; Müller, MA; Merten, L; Böhmer, C; Institut für Biologie, Humboldt Universität zu Berlin, Berlin, Germany., Département Adaptations du Vivant, Muséum National d'Histoire Naturelle, France.; *john.nyakatura@hu-berlin.de*

Analysing form and function of the cervicothoracic transition in

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cetartiodactyls confirms the 'functional elongation hypothesis' of the giraffe neck

The giraffe neck is an icon of evolutionary biology. While giraffes maintain the usual mammalian cervical number of seven vertebrae, their 1st thoracic vertebra (T1) exhibits aberrant anatomy and has been hypothesized already more than a century ago to functionally elongate the neck. We quantitatively test this 'functional elongation hypothesis' by combining phylogenetically informed analyses of neck length, three-dimensional (3D) vertebral shape, and of the functional significance of shape differences across a broad sample of cetartiodactyls. 3D bone models of the cervical series and cervicothoracic transition were analysed. 3D geometric morphometric analysis revealed that the shape of the 7th cervical (C7) has converged in several long-necked species, however, we find unique homeotic shifts that result in a 'cervicalization' of the giraffe's T1. For the European bison, we demonstrate a 'thoracalization' of C7. Other giraffids (okapi and extinct Sivatherium) did not exhibit such 'cervicalized' T1 morphology. Quantitative range of motion (ROM) analysis at the cervicothoracic transition in our sample confirms the 'functional elongation hypothesis' for the giraffe in terms of increased mobility, especially in regard of dorso-ventral flexion/extension. Other factors related to the unique morphology of the giraffe's cervicothoracic transition such as neck posture and intervertebral stability may have also contributed to giraffe neck evolution.

10-3 O'Donnell, MK*; Lunghi, E; Deban, SM; Brown University, Chinese Academy of Sciences, University of South Florida; *mary_kate_odonnell@brown.edu*

Cling performance and contact area in European Hydromantes (Speleomantes) salamanders

Hydromantes are lungless salamanders which depend on cool temperatures and high levels of moisture to maintain the diffusion of oxygen across the skin surface. In the Mediterranean, these salamanders spend a large proportion of their life in caves, climbing on the walls and occasionally the ceiling. Clinging and climbing enable them to access deep, vertical, or elevated portions of the cave interior where suitable temperature, humidity, and nesting sites are found. Daily and seasonal variation in habitat

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conditions may require movement within the caves, as well as movement to more abundant food sources outside. Within the eight European *Hydromantes* species, three species (*H. flavus*, *H. sarrabusensis*, and *H. supramontis*) have been shown to exhibit positive-allometric growth in foot surface area with ontogeny, suggesting that foot area may play an important role in adult survival. However, the relationship between cling performance and foot contact area has not been explored. Here we measure maximum cling angle and contact area in five species of *Hydromantes*, including three with positive allometry of foot webbing. We examine how species which do or do not exhibit allometric scaling of foot surface through ontogeny differ in maximum cling performance on a smooth surface. We found that allometrically scaling foot surface area did not significantly improve cling performance. Foot surface area in some species contributes only a small fraction of the total contact area during clinging, which includes much of the ventral body surface. The use of the ventral body surface by salamanders may allow flexibility in the use of feet for adhesion during clinging, which may impact how selection acts on foot morphology.

58-8 O'Reilly, L*; Dalesman, S; Akanyeti, O; Aberystwyth University; *lio4@aber.ac.uk*

Does learning style affect performance and plasticity in shoaling fish?

It is a widespread phenomenon that individuals from the same population will differ in their speed and ability to learn and yet very few studies looked at why such variation occurs. One hypothesis is that individuals prioritise new environmental cues (current information) and previous experiences (old information) differently. For example, those that favour old information, may be slower to adapt to current information and struggle to repeat success on a task when the context is changed. To test this hypothesis, we presented the three-spined stickleback (*Gasterosteus aculeatus*) with a two-choice associative learning task. The correct chamber was randomised so that success was dependent on using an ecologically relevant landmark as an indicator of food location. Fish were given 45 trials to make 8 out of 10 correct decisions in a row (i.e. learning criterion) before they were presented with a second learning task, which was identical to the first except with

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a new landmark. To evaluate learning performance, we looked at number of trials required to reach criterion and time to find food. To test whether information use correlate with learning success, we analysed how food location and choice from previous trials affect the most recent choice and how this varies over time and across tasks between fast and slow learners. Our preliminary results suggest over time all fish made quicker decisions and find food faster. In task 2, the majority of fish reached criterion faster and showed less variation in performance suggesting information transfer from task 1 to task 2. The goal of this research is to better understand whether learning style affects performance; individual's ability to acquire new information and adapt to new environments.

18-9 Ogilvie, JGO*; Van Belleghem, S; Range, R; Chouteau, M; Counterman, BA; Auburn University, Al; *jgo0012@auburn.edu*

The evolution of polymorphic mimicry in Heliconius butterflies

Mullerian mimicry is a widely studied phenomenon in evolutionary biology. The theory predicts that when multiple warning signals coexist, they will tend to converge to the most common signal through frequency-dependent selection. Heliconius butterflies are a renowned example of Mullerian mimicry yet they present a peculiar paradox, in that several Heliconius species have diverged into an array of distinct warning phenotypes, instead of converging on any one specific warning coloration. The result is that in any specific location numerous unique mimicry rings can be found. However, some species have evolved the ability to maintain multiple mimetic warning phenotypes in a single population, a phenomenon known as polymorphic mimicry. In these populations, the distinct morphs actually belong to different local mimicry rings. The selective pressures that allow polymorphic mimicry to evolve and be maintained remain largely unresolved. Using artificial models of Heliconius doris, which displays such polymorphic mimicry, we quantify predation across sites with varying mimicry rings in French Guiana and Panama. We use these predation experiments to test specific predictions about the selective pressures involved in the maintenance of polymorphic mimicry in H. doris. We find clear evidence of frequency-dependent selection maintaining alternative morphs in the presence of differing mimicry rings. We also find

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evidence of divergent selection on warning color patterns, resulting in marked difference of morphs in different geographic populations. We propose that these predation forms not only contribute to the maintence of polymorphic mimicry within H. doris, but also may promote intraspecific warning diversity of co-mimics, thereby providing insight into the selective forces driving the paradox of warning color diversity among Heliconius butterflies.

35-2 Ohmer, MEB*; Hammond, TT; Switzer, S; Paciotta, E; Coscia, J; Richards-Zawacki, CL; Washington University in St. Louis, University of Pittsburgh; *m.e.ohmer@gmail.com*

Developmental environment has lasting effects on amphibian behavior and thermal physiology

Environmental change during development can result in long term effects on individual physiology and behavior, with implications for disease and predation risk. We examined the effects of simulated pond-drying and elevated water temperatures on development, thermal physiology, and behavior in a widespread North American amphibian, *Rana sphenocephala*. Tadpoles were raised in outdoor mesocosms under warming and drying regimes based on projected climatic conditions. We predicted that amphibians experiencing rapid pond drying and elevated pond temperatures associated with climate change would accelerate development and demonstrate long-term differences in physiology and exploratory behavior post-metamorphosis. Both drying and warming accelerated development and reduced survival to metamorphosis. In addition, frogs with shorter larval periods had lower critical thermal minima and maxima. We also found that developing under warming and drying resulted in a less exploratory behavioral phenotype, and that drying resulted in warmer thermal preferences. Furthermore, behavioral phenotype predicted thermal preference, with less exploratory animals selecting warmer temperatures. Our results indicate that early developmental environments can impact behavior and physiology later in life. This is important because thermal preferences can influence disease risk through behavioral thermoregulation, and an exploratory phenotype may increase risk of predation or pathogen encounter. Due to their potential impacts on thermal physiology and behavior, in combination with previously documented effects on immune function, climatic stressors during

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development may alter amphibian exposure and susceptibility to predators and pathogens into adulthood.

23-9 Ojo, O*; Shoele, K; FAMU-FSU College of Engineering Tallahassee; *oluwafemi1.ojo@famu.edu*

Load reduction and reconfiguration capabilities of branched trees

Trees often fail as a result of wind-induced stresses. During harsh storms, the branching mechanism plays an important role in the stress distribution and stability of trees subjected to such stresses. Eloy in PRL 2011, showed that Leonardo da Vinci's original observation stating the total cross-section of branches is conserved across branching nodes is the optimal configuration for resisting wind-induced damage in rigid trees. The optimal branching pattern of trees and their tendency to break is a function of their reconfiguration capability and the process they employ to reduce high wind-induced hotspots. Through developing an efficient numerical simulation of rigid and flexible branched trees, the role of flexibility and branching patterns on stress mitigation and tree reconfigurations are studied. Our results show that the cross-sectional changes in the branching nodes, the overall tree geometry and flexibility play an important role in predicting tree breakage at each level of branching from the stem to the top branch. This study demonstrates that for a wide range of flexibility, an optimal branching law exists for both flexible and rigid trees wherein uniform stress distribution occurs throughout the height of the tree. For very flexible trees, the prediction of the optimal branching deviates from the aforementioned pattern and is greatly affected by tree reconfiguration. Acknowledgment: This work is supported by the National Science Foundation Grant Number CBET1943810

40-1 Olberding, JP*; Deban, SM; University of California, Irvine, University of South Florida; *olberdij@uci.edu*

Thermal biomechanics

Temperature influences many physiological processes that govern life by way of the thermal sensitivity of underlying chemical reactions. The repeated evolution of endothermy and widespread behavioral thermoregulation in animals highlight the importance of

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elevating tissue temperature to control the rate of chemical processes. Yet movement performance in animals that is robust to changes in body temperature has been observed in numerous species. This thermally robust performance appears exceptional in light of the well-documented effects of temperature on muscle contractile properties. Here we propose that thermal robustness of movement is a general feature of any organismal system, spanning kingdoms, in which mechanical processes replace or augment chemical processes. The use of recoiling elastic structures to power movement in place of direct muscle shortening is one of the most thoroughly studied mechanical processes; using these studies as a basis, we outline an analytical framework for detecting thermal robustness relying on the comparison of temperature coefficients (Q_{10} values) between chemical and mechanical processes. We then highlight other biomechanical systems in which thermally robust performance that arises from mechanical processes may be identified using this framework.

41-1 Olsen, AM; Brown University; *aarolsen@gmail.com*

Translating fish skull science into a product: My first year launching an employee-owned animal anatomy and mechanics bio-design company

Members of our society who are not pursuing academic positions face the challenge of finding employment opportunities in which we can continue to pursue and apply our expertise. Added to this, in so many places of employment, decisions are not made democratically and compensation and ownership are concentrated mostly among those at the top, often benefiting the most privileged members of the organization. A third challenge faced by all members of our society is the limited avenues for science communication: mostly news, social media, and film media. In response to these three challenges, since January 2020 I've been planning an employee-owned company (worker cooperative) to design and manufacture educational products that engage the public in the basic science of animal anatomy, motion, and mechanics. In this presentation I'll share a first product prototype, a kinetic model of an animal that can be assembled and disassembled and when assembled can be moved like a real specimen. The model is constructed from laser cut textiles and 3D printed bioplastic, representing ligamentous and skeletal

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structures, respectively. I designed the components based on photogrammetry reconstructions of a dissected specimen. The product will also include an assembly manual with a graphic narrative of an actual scientist, who will share their story and work as a scientist. This is just one of several potential products and I am currently seeking co-founders, in particular those underrepresented in STEM. I encourage any SICB members interested in joining to please contact me. It is my hope this company will be an active member of the SICB community, providing a diverse, empowering, and inclusive workplace for members to find new ways to share our passion for animal structure, mechanics, and natural history. And to have as much fun as possible while doing so.

8-10 Olson, EGN*; Gray, JR; Wiens, TK; University of Saskatchewan; *erik.olson@usask.ca*

A computational model of locust visual motion detection incorporating global and feedforward inhibition

Detection of looming obstacles is vitally important to all animals for avoiding predators, conspecifics, and environmental obstacles. The migratory locust, *Locusta migratoria*, possesses a well-characterized neuron in each optic lobe known as the lobula giant movement detector (LGMD) which integrates visual data into a signal encoding the imminence of collision with an approaching object. While this neuron itself and certain portions of its input network are well-studied from both physiological and modelling perspectives, certain physiological discoveries in recent literature have not yet been reflected in computation models of locust looming detection. Specifically, the posited role of global inhibition in normalizing inputs has not been investigated computationally, and new characterizations of neurons providing feedforward inhibition to the LGMD have not been incorporated into models. Considering this, a model was developed combining features from past literature examples with recent anatomical reconstructions based on neural recordings. This model, consisting of a simulated LGMD neuron and its relevant inputs in the retina, lamina and medulla, will be tested for its ability to replicate features of LGMD responses to more complex looming trajectories which were observed in recent studies - specifically, responses to changes in the velocity of an approaching object. Moreover, the

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implications of the model regarding the posited physiology of feedforward and global inhibitory elements will be discussed.

104-5 Olson, RA*; Montuelle, SJ; Curtis, H; Williams, SH; Ohio University, Ohio University Heritage College of Osteopathic Medicine; *rachel.olson.phd@gmail.com*

Sucking and lapping in mammals: a false dichotomy?

Two of the main mechanisms of fluid acquisition in adult mammals are lapping and sucking. Mammals with incomplete cheeks ingest fluid via lapping, which involves rhythmic tongue protrusion to contact the fluid and retraction to transport the fluid stream into the oral cavity. In contrast, mammals with complete cheeks use suction by generating negative pressures to draw fluid into the oral cavity. Here we use XROMM combined with a soft-tissue marker in the tongue to compare jaw and tongue kinematics and coordination during drinking in species with incomplete cheeks (ferret) and complete cheeks (pig and goat). Results demonstrate that lapping uses highly coordinated out-of-phase tongue-jaw movements, such that the tongue is maximally protracted at maximum gape. The goat also shows highly correlated, but in-phase, tongue-jaw movements, such that the tongue is maximally protracted at minimum gape. Further, the tongue never leaves the oral cavity. Surprisingly, tongue-jaw kinematics in the pig differs from the goat in key ways: the tongue often protrudes into the fluid as in lapping, but tongue-jaw coordination is in-phase, as in sucking. Additionally, the pig does not swallow every cycle as in the goat. As tongue-jaw coordination is also weak in the pig, unlike in the goat, these results show fundamental differences in sucking between two closely related species. This also demonstrates that the historical dichotomy of lapping and sucking is not representative of the kinematic diversity underlying mammalian fluid ingestion.

39-10 Orbach, DN*; Brassey, CA; Gardiner, JD; Brennan, PLR; Texas A&M University-Corpus Christi, Manchester Metropolitan University, University of Liverpool, Mount Holyoke College; *dara.orbach@tamucc.edu*

Three-dimensional shape analysis with no landmarks: Insights from marine mammal vaginas

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For structures lacking homologous landmarks, limited approaches are available to compare 3D shapes and discern evolutionary patterns. Instead of comparing shape variation, we used alpha shape analyses to quantify vaginal complexity in 40 marine mammal specimens. Additionally, we explored phylogenetic signal and the potential roles of natural selection and sexual selection on 3D vaginal shape evolution. Complexity scores were consistent with qualitative observations. Cetaceans had a broad range of alpha complexities, while pinnipeds were found to be comparatively simple, and sirenians were found to be complex. Surface shape complexity was driven by invaginations and protrusions of the vaginal wall. Despite intra-specific variation in vaginal shape, there was some species-level grouping in complexity within PCA morphospace. Significant phylogenetic signal, however, was absent from the data. Metrics of natural selection (relative neonate size) and sexual selection (sperm competition risk, sexual size dimorphism, and penis tip morphology) did not explain complexity patterns. Additional metrics, such as penile shape complexity, may yield interesting insights into marine mammal genital coevolution. We advocate for the use of alpha shapes to discern patterns of evolution that would otherwise not be possible in 3D anatomical structures lacking homologous landmarks.

83-4 Orr, SE*; Buchwalter, DB; North Carolina State University; *seorr@ncsu.edu*

Physiological plasticity of the mayfly, N. triangulifer, in response to salinity stress in freshwater ecosystems

Freshwater salinization is a rapidly emerging ecological issue and is correlated with significant declines in aquatic biodiversity. It remains unclear how changing salinity regimes affect the physiology of sensitive aquatic insects, such as mayflies. We used the parthenogenetic mayfly, *N. triangulifer*, to ask how ionic exposure history alters physiological processes and responses to subsequent major ion exposures. Using radiotracers (^{22}Na and $^{35}SO_4$), we observed that mayflies reared in dilute control water (16 mg L^{-1} Na and 23 mg L^{-1} SO_4) and subsequently transferred to elevated salinities (153 mg L^{-1} Na or 667 mg L^{-1} SO_4) had 2-fold ($p<0.0001$) and 8-fold ($p<0.0001$) greater ion uptake rates than mayflies chronically reared in elevated Na or SO_4, respectively. Ca transport was uniformly much

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lower and was minimally influenced by exposure history. With qRT-PCR, we observed that the expression of many ion transporter genes in mayflies was influenced by elevated salinity in an ion-specific manner (upregulation in response to SO_4, downregulation in response to Ca). Elevated Na exposure had minimal influence on the same genes. Finally, we demonstrated that acute NaCl (1850 mg L^{-1}) toxicity was reduced by 45% in 10-day old mayfly larvae that had been reared in slightly elevated NaCl (481 mg L^{-1}) compared to control-reared siblings ($p<0.01$). Similar acclimatory toxicity bioassays are ongoing for Ca and SO_4 challenges. Modest physiological changes in chronic salinity exposure suggest some acclimation, but may not suffice in multistressor conditions common in nature. Overall, this project provides evidence that exposure history to elevated salinity modifies physiological processes (e.g., ion flux and gene expression) and the resultant major ion toxicity in *N. triangulifer*.

55-6 Orr, KP*; Reiss, JO; Humboldt State University; *kyle.orr@humboldt.edu*

The morphology of gills and the associated vessels of two larval amphibians, Dicamptodon tenebrosus and Ascaphus truei, and the lungfish Lepidosiren paradoxa

Vertebrate gills may be either external (protruding from the body surface) or internal (enclosed in a chamber). Among living amphibians, external gills are found in salamander larvae and neotenes, early frog larvae, and caecilian embryos; internal gills are found only in later-stage frog larvae. Evidence for internal gills has also been found in stem tetrapods, and amphibian-like external gills have been found in some fossil temnospondyls and anthracosaurs. Gill homology among these groups and life stages has long been questioned. To address this, we used scanning electron microscopy, vascular casting, and paraffin sectioning to study the morphology of gills and associated vessels of three sarcopterygian species: the basal frog *Ascaphus truei*, the salamander *Dicamptodon tenebrosus*, and the lungfish *Lepidosiren paradoxa*. In all three species, blood flows from the heart through four pairs of afferent branchial arteries, through the gill lamellae, and drains through efferent branchial arteries into the dorsal aorta. In *D. tenebrosus* and *A. truei* no gill lamellae are found on the fourth

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branchial arch; instead, the afferent branchial artery supplies blood to the lung. In the external gill of *D. tenebrosus* the afferent arteries travel posterolaterally within an elongation of the septum and protrude dorsolaterally from the body, supplying blood to the paired, digit-like lamellae via a single vascular loop per lamella. *A. truei*, unlike most anuran larvae, never develops external gills, but only internal gills. These extend directly from the ventral side of the branchial arches. Each lamella has multiple club-like branches, each housing a vascular loop. These findings shed light on the morphology and evolution of sarcopterygian gills.

54-3 Ortega-Jimenez, VM*; Sanford, PC; Kennesaw State University; *ornithopterus@gmail.com*
Turning liquid into vapor: Knifefish's powerful suction-feeding
We discovered that Knifefish (*Apteronutus albifrons*) can generate cavitation bubbles using a powerful rapid suction while feeding from a capillary tube. In this way, knifefish can draw a potent jet of water into the mouth that is ~450 Gs (acceleration due to gravity). Cavitation Number calculated on flow acceleration was less than one (average Ca ~ 0.65), which indicates cavitation occurrence. Furthermore, when fish were allowed to suction feed from a capillary tube sealed at one end, we observed large cavitation bubbles appear and collapse in less than 22 ms. A hammer-like sound was recorded, which coincides with bubble collapse. DPIV measurements indicate that knifefish can generate a ~ 3 mm suction range with flow speeds up to 2.5 m/s in less than one millisecond. We suggest that cavitation may serve knifefish in the immobilization, dislodgement, and capture of prey, as well as a detection method for small prey hidden in narrow refuges. Thus, cavitation exploitation may be more widespread among suction-feeding organisms than has been previously thought.

105-5 Ortiz , FD*; Buser, T; Hall, K; Kolmann, M; Donatelli, C; Denison University, Oregon State University, University of Washington, Friday Harbor Labs, University of Michigan, University of Ottawa, Department of biology; *ortiz_f1@denison.edu*
Flight of Daedalus: Kinematics of demersal swimming in the fish superfamily Cottoidea

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Sculpins (Superfamily Cottoidea) are a diverse clade of fishes found across an array of marine and freshwater habitats including submarine canyons, rivers, kelp forests, deep open waters, and tidepools. These varied habitats beget a wide variety of swimming modes, from dorsal fin undulators to pectoral rowers, and despite most sculpins living along the benthos, some taxa from Lake Baikal are pelagic. This diversity of swimming modes, combined with variable morphologies, may speak to the diverse microhabitats these fishes fill. In this study we evaluate how shape and morphology have shaped swimming kinematics in thirteen species across three cottoid families. Using Matlab, we extracted kinematics from those videos including swimming speed (BL/s), tail beat frequency (Hz), and body amplitude (BL). After swimming trials, we CT (computed tomography) scanned individual specimens and measured a range of morphometric variables including head width, caudal peduncle height, aspect ratio, tail length, pelvic fin length and pectoral fin length, which are proven metrics that relate to swimming performance. Finally, we used phytools in R to show how different traits and behaviors evolved over time across the sculpin phylogeny. Our results reveal that sculpin with smaller heads, reduced peduncle height, and smaller pectoral fins relative to their body size swam significantly faster than those sculpins with larger relative lengths.

110-4 Ospina-Rozo, L*; Stuart-Fox, D; University of Melbourne, Melbourne, Australia; *lospinarozo@student.unimelb.edu.au*

Environmental factors shaping visible and near-infrared light manipulation in Christmas beetles

The ability to manipulate light influences the relationship between an organism and its environment in multiple ways. Manipulation of visible wavelengths has generally been associated with signaling and camouflage, while near-infrared (NIR) light manipulation primarily influences thermoregulation because these wavelengths cannot be seen by animals. The association between reflectance in these different wavebands and environmental variables can therefore reveal the relative importance of different selective pressures; yet the NIR is seldom measured or considered. We examined the association between reflectivity in visible (400 - 700 nm) and NIR (700 - 2000 nm) wavelengths and environmental variables such as

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temperature, humidity, radiation and vegetation cover for 219 individuals from 59 species of Christmas beetles (Scarabeidae: Rutelinae) distributed across Australia. We found that visible reflectivity was higher in environments with hotter summer temperatures but there was no relationship between climate and NIR reflectivity, once we had accounted for variation in visible reflectivity. These results suggest that selection for thermal benefits is not the primary driver of reflectance properties in Christmas beetles. Instead, the remarkable diversity of light manipulation in both NIR and VIS light in this group may be driven by selection for other functions. Our study highlights the utility of comparing visible and invisible NIR wavelengths to understand ecological factors shaping the extraordinary diversity of animal coloration.

S11-3 Ostrander, EA*; Parker, HG; Evans, JM; Plassais, J; Dreger, D; Harris, A; Davis, BW; McIintyre, JK; Cairns, KM; Ali, BM; Hogan , AW; National Institutes of Health, Bethesda MD, USA, University of Rennes 1, Rennes France, National Institutes of Health, Bethesda, MD USA, Texas A&M University, College Station, TX, USA, New Guinea Highland Wild Dog Foundation, St. Fernandina Beach, FL, USA, University of New South Wales, Sydney, NSW, Australia.; *eostrand@mail.nih.gov*

Big and small, short and tall, dog genes tell all

The domestic dog has undergone intensive human-driven selective pressure to produce canines of a particular appearance and behaviors. The result has been the development of over 350 modern breeds, most with human or geographic- induced barriers to gene flow, resulting in fixed traits that reliably track through multiple generations. Recent studies in our lab have focused on decoding the genetic basis of morphologic traits that both vary between and define dog breeds. That work demonstrated a now recurring theme in dog genetics; many highly variable phenotypes are controlled by variation in small numbers of genes, as opposed to humans, where subtle differences in phenotype tend to be controlled by large numbers of variants. As we show, this difference likely represents the recent development of most breeds within the last 300 years in Western Europe. In this study, we describe whole genome sequence analysis (WGS) of over 1000 dogs,

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identifying genes for morphology, aging, and a host of other traits. Since disease susceptibility is one of the ways in which dog populations are most well-poised to inform human health, we also applied our analysis of canine WGS to canine cancer, demonstrating the presence of genes that serve as drivers of tumor growth. Finally, we examine a population of dogs thought to be extinct in the wild, demonstrating the utility of genomic approaches for understanding canine history and relatedness.

BSP-1-4 Ostwald, MM*; Fox, TP; Harrison, JF; Fewell, JH; Arizona State University, Tempe, AZ; *ostwald.madeleine@gmail.com*

Sociality confers energetic savings in a facultatively social bee

Social groups form when the costs of breeding independently exceed fitness costs imposed by group living. The costs of independent breeding can often be energetic, especially for animals performing expensive behaviors, such as nest construction. To test the hypothesis that nesting costs can drive sociality by disincentivizing independent nest founding, we measured the energetics of nest construction in a facultatively social carpenter bee (*Xylocopa sonorina), which bores tunnel nests in wood. We used flow-through respirometry to measure metabolic rates of bees excavating wood and used computerized tomography (CT) images of nesting logs to measure total excavation volumes. From these data, we estimated the energetic cost of nest construction under alternative social/reproductive strategies. Our results indicate that new-nest excavation entails a significant energetic cost, equivalent to approximately 150 hours of flight. Alternatively, a female may minimize or even eliminate this cost by inheriting an existing nest, a strategy associated with group living. These results suggest that females join (or remain in) social groups to avoid steep energetic costs, supporting the costly nest-founding hypothesis for the origins of group living.*

73-3 Othayoth, R*; Francois, E; Li, C; Johns Hopkins University; *ratan@jhu.edu*

Large spatiotemporal scale measurement of cockroach traversal of large obstacles

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Insects can traverse natural terrain filled with obstacles comparable to or larger than their body size. Understanding how their movement and behavior emerges from interaction with complex 3-D terrain is challenging, especially at large spatiotemporal scales. Existing terrain testbeds limit observations to small scales (~10 strides, ~10 body lengths) and low spatial resolution (~3% pixels representing the animal). Here, we used a recently-developed terrain treadmill to perform high-resolution observations of discoid cockroaches moving through large obstacles over large spatiotemporal scales. The terrain treadmill consists of a transparent outer sphere and a concentric inner sphere mounted with large obstacles and uses feedback control to keep an untethered moving animal on top. We studied how the animal traversed sparse and cluttered pillar obstacles. In a single trial, each animal moved on the terrain treadmill continuously for ~500 seconds (~2500 strides) covering ~50 m (~1000 body lengths), changing direction freely (as opposed to only forward movement on traditional treadmills). The higher spatial resolution (~10% pixels representing the animal) enabled us to reconstruct the animal's 3-D motion in the terrain and estimate contact of its body and antenna with obstacles. For cluttered pillars, the animal almost always traversed by rolling its body into gaps and with body-pillar interaction. For sparse pillars, interaction reduced due to wider gaps and use of antennae to detect and avoid obstacles. Apart from walking and running, the animal displayed behaviors such as antenna sweeping, body rolling/turning, and pillar climbing. Our study established a new experimental system for measuring large obstacle traversal behavior with a high spatial resolution over a long duration and distance.

73-2 Othayoth, R; Li, C*; Johns Hopkins University; *chen.li@jhu.edu*
Simultaneous wing opening and leg flailing enables strenuous ground self-righting in cockroaches
Self-righting when flipped over on the ground is strenuous for many terrestrial animals. During self-righting, the discoid cockroach often pushed its wings against the ground to begin a somersault by pitching up its body. However, despite repeated wing opening attempts, the animal rarely somersaulted successfully but instead often rolled to its side to self-right. Its legs flailed frequently

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and desperately in this process. Here, we studied whether simultaneous wing opening and leg flailing is beneficial. We tested a robot with two wings and a pendulum leg that swings laterally. We chose wing opening and leg oscillation amplitudes to generate similar strenuous self-righting behavior as the animal's (no successful somersault, probabilistic self-righting via rolling). As wing opening and leg flailing amplitudes increased, self-righting probability increased. We used a potential energy landscape model to quantify the potential energy barriers to self-right. Without leg flailing, the pitching kinetic energy generated by wings pushing against the ground was insufficient to overcome the high barrier to self-right by pitching. Similarly, without wing opening, the rolling kinetic energy fluctuation generated by leg flailing was insufficient to overcome the small barrier to self-right by rolling. However, when used together, wing opening reduced the rolling barrier and enabled the kinetic energy fluctuation from leg flailing to probabilistically induce barrier-crossing, resulting in self-righting by rolling. Our study demonstrated that animals and robots can modify their potential energy landscapes to facilitate locomotor transitions using kinetic energy fluctuation. It also suggests that appendage coordination is important during strenuous self-righting (see Xuan and Li, 2020, *Bioinsp. Biomim.* and *IEEE Rob. Auto. Lett.*).

42-2 Ouyang, JQ; University of Nevada Reno; *jouyang@unr.edu*
What determines an urban bird? Genetic inheritance and endocrine plasticity
As urban areas continue to expand globally, understanding how and why species respond to novel habitats becomes increasingly important. Knowledge of the mechanisms behind observed phenotypic changes in urban animals will enable us to better evaluate the impact of urbanization on current and future generations of wildlife. Physiological changes, such as those involved in the endocrine stress response, may allow individuals to inhabit and thrive in urbanized areas, but it is currently unknown how these changes arise in natural populations. In this study, we performed a 4-way crossfoster experiment in free-living house wren chicks, Troglodytes aedon, to disentangle whether differences in baseline corticosterone between urban and rural individuals is a result of

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genetic and/or plastic mechanisms during development. We found that urban chicks already had higher corticosterone levels than their rural counterparts on the day they hatched, which suggests a possible genetic component to the corticosterone phenotype. However, rural offspring that were moved to an urban environment significantly increased their corticosterone levels, mimicking those of urban offspring. Our findings suggest that, although differences in baseline corticosterone concentrations between urban and rural individuals may have a genetic component, plasticity plays a pivotal role and can modify the corticosterone phenotype in response to the environment experienced in the first two weeks of life.

1-4 Owens, ACS*; Lewis, SM; Tufts University, Department of Biology, Medford, MA; *avalon.owens@tufts.edu*

Festival of lights: The ecological benefits of monochromatic illumination vary by insect taxon

The expansion of human activity into natural habitats necessitates the introduction of artificial light at night, which can severely impact local fauna. In recent years, advances in LED technology have enabled the spectral tuning of artificial light sources, which could in theory limit their impact on vulnerable organisms. However, resulting experimental comparisons of candidate eco-friendly colors have mostly considered only one type of fitness effect, and often on only one species. Herein we expose synchronously flashing *Photinus carolinus* fireflies at a popular ecotourist site to downwelling illumination of three colors (blue, amber, and red) and record the impact on male courtship flash activity, as well as the degree to which the lights attract flying insects. Our results suggest that spectral tuning has been overpromised as a conservation solution. Instead, dimming, shielding, and otherwise limiting artificial light in both space and time is likely the best method of minimizing its impact on natural habitats.

18-5 Ozkan Aydin, Y; Goldman, D; Bhamla, S*; Georgia Tech; *daniel.goldman@physics.gatech.edu*

Collective locomotion in entangled worm and robot blobs

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Living systems at all scales aggregate in large numbers which consist of unconnected individuals that collectively flock, school or swarm. However, some aggregations involve physically entangled individuals, which can confer emergent mechanofunctional material properties to the collective. Here, we study in laboratory experiments and rationalize in theoretical and robotic models the locomotor dynamics of physically entangled and motile self-assemblies of centimeter long California blackworms (*L. variegatus*). We specifically focus on how worm blob can break symmetry to move across a substrate under thermal gradient. Depending on the position in a blob, individual worms encounter different thermal stimuli. We observe that in a small blob (N= 20), worms facing the cold side act as pullers, in contrast the worms closer to the hot side are coiled to lift the back of the blob. As the blobs increase in number (N>300), we observe that the blob moves at a slower speed compared to smaller blobs, but the movement becomes more consistent compared to the relatively jerky pull events observed in smaller blobs. We hypothesize that an entangled collective can exhibit emergent locomotion via three principles: mechanical interactions (entanglements), differentiation of roles in the collective, and the existence of binders. To test this, we developed robophysical blobs which programmed to model high (crawl) and low (wiggle and binder) stimulus behaviors of worms. Our results reveal that (1) gait differentiation is critical for collective movement, but synchronization is not required, and (2) reduced activity of the robots enhances the physical entanglement between individuals. This combination enables the robot blob to move as a collective without sophisticated control of individuals.

24-11 Ozkan-Aydin, Y*; Aydin, E; Chong, B; Goldman, DI; Georgia Tech; *yasemin.ozkanaydin@physics.gatech.edu*

Advantages of limb-body coordination and passive body structures in a myriapod robophysical model

Multi-legged animals such as centipedes move effectively in diverse terrain; limb-body coordination and flexible body parts allow them to morphologically adapt to the environment. To understand the importance of body morphology and complex, dynamic interactions between an organism and its environment, we built a low-cost multi-legged hybrid (containing soft and hard components) 70 cm robot

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which has 8 segments, each with two limbs driven out of phase. The back elements and limb pairs are driven by servo motors. Building on theoretical results from geometric mechanics, we systematically tested gait patterns with different leg contacts and body undulations on laboratory environments including flat and uneven rigid ground. On flat ground, the robot with rigid components moved in the same way as the theoretically predicted gaits. As the roughness of the surface increased, the robot's performance suffered (and theoretical predictions became unavailable) due to deleterious interactions like jamming of limbs. However, addition of directional compliance into the robot's legs and soft elements at two body segments improved the open-loop locomotion performance (often to levels of that on flat ground) by either reducing the effects of environmental disturbances or increasing stability. Remarkably, without sensing and active feedback, the robot can traverse complex terrestrial ground like grass, leaf litter and stair-steps, pointing yet again to the importance of mechanics in control of locomotion.

106-6 Pac, JM*; Maranto, D; Medina, M; Kerwin, AH; McDaniel College, Pennsylvania State University; *jmp005@mcdaniel.edu*
Comparative genomics reveals differences between coral-associated and free-living bacteria
Reef building corals, such as *Orbicella faveolata*, are the foundation for essential marine habitats. These corals depend on a complex symbiosis between the coral host, bacterial microbiome, and photosymbionts (Symbiodiniaceae). To examine the genomic potential of coral bacterial symbionts we assembled the genomes of nine *O. faveolata* bacterial isolates via KBase, and annotated the genomes using RAST's annotation server. The subsystem features found in each genome were assessed via SEED viewer and compared to 33 previously published phylogenetically related genomes (including 13 host-associated and 20 free-living bacteria) from NCBI. Eight of the nine coral-associated bacterial genomes included the complete biosynthesis pathway of essential amino acids, including threonine and leucine. An ANOVA analysis of the subsystem features was used to narrow down the more important features contributing to the host-associated lifestyle for each phylogenetic group, and those features were then visualized using a PCA analysis. The subsystem

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features contributing to the host-associated lifestyle varied by phylogenetic group, but included genes associated with amino acid biosynthesis, stress response, and transporters, among others. The presence of essential amino acid biosynthesis pathways suggests that these coral-associated bacteria could be nutritional symbionts of *O. faveolata*. Using a comparative genomics approach allows us to more comprehensively examine the potential contributions of coral bacterial symbionts. At a time when tropical corals are under increasing threats, a more in-depth understanding of the interactions between members of this complex symbiosis will aid in our efforts to support and rescue coral reefs.

24-8 Paez, L*; Melo, K; Ijspeert, A; EPFL, KM-RoBoTa Sarl; *laura.paez@epfl.ch*

Performance tradeoffs in anguilliform swimming via viscoelastic modulation

Through a chain of rigid actuators, roboticists are capable to closely replicate the morphology and the kinematics of anguilliform swimmers like lampreys. However, a robot is mainly composed of rigid structures while the animal's body is composed of soft tissues with viscoelastic mechanical properties. In this work we use a simple muscle model to generate an input torque signal that drives the robot's motors providing them with viscoelastic properties. The model has three components. An activation gain that represents the active element, stiffness and damping terms that represent the passive elements. Twenty representative tests were run and a second order model was fitted following the Response Surface Method. Using this methodology the steady state velocity, acceleration, power consumption and Cost of Transport (CoT) are evaluated as proxies for the swimmer's performance. Our results show that different velocities can be achieved only by modulating the activation signal (i.e. without taking into account the stiffness and damping values). However, high velocities come at the cost of high power consumption and CoT. Modulating stiffness then helps lower CoTs and power consumption during steady state swimming, reaching a performance similar to those of a real animal. Interestingly, the stiffness also improves the peak acceleration which is important for escape responses. On the other hand, increments of damping have improvements in CoT. However, the

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internal damping of the mechanical components of the robot, presents higher damping values than their animal counterparts. Our results show that a swimming robot using a muscle model is able to reproduce the dynamics of an eel swimming at low frequency and velocity.

5-8 Palaoro, AV*; Peixoto, PEC; Federal University of São Paulo, Brazil , Federal Univeristy of Minas Gerais, Brazil; *alexandre.palaoro@gmail.com*

Can size and performance tell us different stories about the role of animal weapons during fights?

From the antlers of deer to the claws of crustaceans, animal weapons exhibit a diversity of shapes and sizes. Some of this diversity might stem from the selective pressures imposed on the weapons from fighting. However, two problems arise when considering that assumption. First, evidence that weapons increase fight success focuses on studies with few species. Second, how weapons are measured vary; while some studies focus on size estimates, others focus on performance components (e.g., strength). To address these concerns, we performed a meta-analysis to compare standardized estimates of how weapons can influence contest success. After scanning 1108 papers and 12 relevant reviews, we totaled 107 effect sizes from 51 species of vertebrates and invertebrates. In these studies, 69.15% (74 out of 107) reported linear estimates of size, while 21.49% (23) reported performance estimates. Interestingly, we found performance estimates mainly for crustaceans and lizards, with only one estimate in crickets. For the effect of weapon size on contests, we used the standardized difference between winners and losers as our effect size; it has been shown that larger differences in a given trait indicate higher contest success. We found that winner and losers differed significantly for size estimates, but found only marginal difference for performance estimates. Additionally, linear estimates had larger differences between winners and losers than performance estimates. Our results thus suggest that size is more important for contest success than performance. However, they also suggest strong biases in the literature, which prevents further understanding of how different proxies can influence weapon evolution and diversification.

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95-4 Palecanda, S*; Steck, M; Porter, ML; University of Hawai'i at Manoa; *spalecan@hawaii.edu*

Opsin expression during development in Gonodactylaceus falcatus: Investigating the role of ultraviolet sensitivity in stomatopod larvae

Stomatopod visual systems are known to be one of the most intricate in the animal kingdom. Their stalked eyes move independently and have multiple spectral and polarization channels. The complex retina responsible for these abilities is only formed during the last phase of larval development during which time the larval retina is lost. It was previously assumed that the eyes of larval stomatopods are simpler than their adult counterparts, however it appears that simpler for a stomatopod can still be remarkably complex. Using transcriptomic analyses, we have determined the opsin proteins which are expressed at larval, post larval (transitional), and adult developmental stages of *Gonodactylaceus falcatus*, a widely distributed tropical and subtropical species. Our data suggests that larval *G. falcatus* may not express a full adult repertoire of opsins at high levels but they do express ultraviolet sensitive opsins at levels consistent with use in vision. The ability to perceive ultraviolet light was previously associated with adult stomatopods only and is known to be used in aggressive or mate-finding interactions. The ecological purpose of ultraviolet light perception in larvae is less clear. A potential role for ultraviolet light perception as a depth guide in daily vertical migration has been suggested but not previously tested in marine crustaceans. Opsin expression at each developmental stage of *G. falcatus* will be compared and evidence for the utility of ultraviolet sensitive opsin expression in larval stages will be discussed. Ongoing work will seek to characterize the response of these larvae to changes in ultraviolet light conditions throughout a daily light cycle.

10-2 Palecek-McClung, AM*; Schoenfuss, HL; Blob, RW; Clemson University, Clemson, SC, Saint Cloud State University, Saint Cloud, MN; *apalece@g.clemson.edu*

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Stick to it: Comparisons of passive adhesion in waterfall-climbing fishes on challenging substrates
In Hawaiian waterfall-climbing gobies, the pelvic fins fuse into a sucker that allows all four species to produce passive adhesion. This allows some species to climb waterfalls 10s-100s of meters in height, resulting in elevation-dependent species stratification. Adhesive performance is likely modulated by a variety of factors including substrate characteristics, sucker morphology, and behavior. We investigated the influence of two substrate characteristics (wettability and roughness) on the passive adhesive performance of four species of waterfall-climbing gobies with varying climbing abilities. Passive adhesion varied by species and substrate, where all species had higher shear pull-off forces on rough substrates than smooth substrates. Moreover, the species found at the highest-elevation stream sites (best climbers) had higher pull-off forces than those found in lower-elevation streams (poor climbers or non-climbers). Differences in passive adhesive performance may explain why some species are capable of invading upstream habitats.

94-2 Palermo, N*; Hershman, M; Proenca, M; Theobald, J; Florida International University; *nicholaspalermo@fastmail.com*
Drosophila melanogaster increase steering errors when relying on restricted-area optic flow fields
Drosophila melanogaster rely on wide-field optic flow fields to detect perturbations from their flight path. Previous research has identified that flies will shift their attention forward during forward flight to discount lateral portions of their visual field that are too noisy due to motion blur. The loss of these large regions of the visual field may be costly to navigating flies. For instance, distinct optic flow fields can have small regions which are highly ambiguous. If flies can sample the optic flow field over the entire visual field, these ambiguities can be reduced. We investigated the effects of restricted-area optic flow fields on fly steering errors. We also looked at which restricted-area regions resulted in the smallest steering errors.

22-5 Pales Espinosa, E*; Allam, B; School of Marine and Atmospheric

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High spatial resolution mapping of the mucosal proteome of the gills of Crassostrea virginica: implication in particle processing

In the oyster *Crassostrea virginica*, the organization of the gill allows bidirectional particle transport where a dorsal gill tract directs particles meant to be ingested while a ventral tract collects particles intended to be rejected as pseudofeces. Previous studies showed that the transport of particles in both tracts is mediated by mucus. Consequently, we hypothesized that the nature and/or the quantity of mucosal proteins present in each tract is likely different. Using endoscopy-aided micro-sampling of mucus from each tract followed by multidimensional protein identification technologies, and *in situ* hybridization, a high spatial resolution mapping of the oyster gill proteome was generated. Results showed the presence in gill mucus of a wide range of molecules involved in non-self recognition and interactions with microbes. Mucus composition was different between the two tracts, with mucus from the ventral tract shown to be rich in mucin-like proteins, providing an explanation of its high viscosity, while mucus from the dorsal tract was found to be enriched in mannose-binding proteins, known to be involved in food particle binding and selection. Overall, this study generated high resolution proteomes for *C. virginica* gill mucus and demonstrated that the contrasting functions of the two pathways present on oyster gills are associated with significant differences in their protein makeup.

38-2 Pamfilie, AM*; Garner, AM; Russell, AP; Dhinojwala, A; Niewiarowski, PH; Stony Brook University, University of Akron, University of Calgary; *amp183@zips.uakron.edu*

Claw morphology impacts frictional interactions on rough substrates

The digits of many anoles and geckos carry adhesive pads and claws, both of which have been posited to allow attachment to the various substrates the lizards encounter. Recent work has suggested the two structures act synergistically, with the adhesive pad adhering best to smooth surfaces and the claw clinging best to rough ones. Previous studies have found correlations between habitat use and claw morphology, but how or if variation in claw morphology alone

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(i.e., without the influence of the subdigital pad) relates to this remains unknown. Here we quantify both natural and induced variation of claw morphology in Cuban knight anoles (*Anolis equestris*) to explore what effects claw form and wear have on inducible frictional forces on select substrates with different roughness profiles. We removed the claws of preserved specimens and quantified their morphology via univariate measures used in previous work (e.g., length, height, curvature) as well as via multivariate geometric morphometrics. Results varied between these approaches. Geometric morphometrics revealed associations between overall shape and clinging force on the rougher substrates. The univariate measures also revealed significant effects of claw characteristics on induced clinging force, but these results were not similar across substrates and were often inconsistent with the morphometric results. Our results suggest that the impact of claw morphology on the clinging ability of lizards varies with substrate and habitat use and support the hypothesis that adhesive lizards achieve attachment differently across substrates, with the two attachment systems interacting synergistically to permit engagement over a continuum of surface roughnesses.

70-8 Pandey, A; Yuk, J; Chang, B; Fish, FE; Jung, S*; Cornell University, Clark University, West Chester University; *sj737@cornell.edu*

Impact force of high diving of animals (dolphins, penguins, frogs) and humans

In nature, many animals dive into water at high speeds; e.g. human diving from cliffs, plunge diving birds, and aquatic animal porpoising and breaching. Especially for humans, extreme sports such as cliff diving or high diving provide excitement, but can be close to the limit of body injuries. For animals, high dives can provide opportunities to find prey, move at high speed, escape from predators, or communicate providing a benefit to the diver despite the potential risk of injury. Because most human diving-related injuries happen during the impact phase, we focus on the dynamics of the water entry, where the unsteady liquid forces are dominant and dependent on the shape of the body. Simplified concave and convex shapes, and 3D-printed elaborate models based on the head and body designs of animals were dropped from a height of 20 - 60

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cm into water to explore a functional relationship between the body shape and the force. The water-entry dynamics were recorded with a high-speed video camera and the impact force was measured from a force transducer. We show that the impulse due to impact, which incorporates the relevant timescale of unsteady forces, varies across the different diving forms and can be responsible for muscle/bone injuries. As such, this study presents a mechanics-based understanding for high diving of animals with various shapes.

40-9 Panessiti, C E*; Albert, A; Konow, N; University of Massachusetts Lowell; *Caitlin_Panessiti@student.uml.edu*

Effects of free versus tethered food presentation on axolotl strike velocity

Aquatic animals used in feeding biomechanics studies are often trained to strike at and procure food that is presented via forceps, instead of catching free-moving food as they would in the wild. It has been suggested that forceps-training of subjects may influence their feeding kinematics, especially movement velocities because as the animals learn that the food is unable to escape, they may not strike at it as fast as they would if the food item was free to move and escape. We sought to determine if forceps-trained axolotls would strike faster at food items that appeared to be free-moving as compared to food items presented via forceps. High speed video recordings were taken of three axolotls feeding on crickets that were presented either via forceps or tied to thin (0.12 mm) and clear weighted monofilament line, and thus appeared untethered to the Axolotl. Recordings of Axolotls feeding on untethered fish were also taken to determine how prey that can easily escape would affect gape velocities during strikes. Mean and peak gape opening and closing velocities were extracted for each food type and presentation and compared using ANOVA. We found no statistically significant differences between the mean and peak gape opening and closing velocities when axolotls fed from forceps as compared to on food that appeared to be untethered (p-values ranged from 0.158 to 0.717). Surprisingly, strikes on goldfish were significantly slower than strikes on crickets, but more data are needed to verify this result as only a few trials were analyzed. These data are important as they show that training aquatic Axolotls to eat off of forceps does not alter movement velocities

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during feeding but suggest that there may be a kinematics response when different food types are used.

95-1 Parkinson, RH*; Kessler, S; Miriyala, A; Wright, GA; Department of Zoology, University of Oxford, Oxford, UK OX1 3SZ, Center for Integrative Genomics, University of Lausanne, Lausanne, Switzerland, Centre for Neural Circuits and Behaviour, University of Oxford; *rachel.parkinson@zoo.ox.ac.uk*

Bumblebee sweet taste is encoded by a population of gustatory receptor neurons

The sense of taste facilitates rapid decisions about whether to ingest or reject food. The extent to which information beyond the basic modalities (e.g. sweet, bitter, salty) is represented by the peripheral taste system has rarely been studied. Carbohydrates are critical nutrients for many insects detected by sugar-sensing gustatory neurons (GRNs) that elicit action potentials (spikes) in response to stimulation. Here, we show that GRN activity on the mouthparts of the buff-tailed bumblebee, Bombus terrestris, represents the molecular identity of sugars. Sugars with the highest metabolic value had the lowest detection thresholds and produced the greatest rate of change in spiking in the most active sugar-sensing GRN. High value sugars also always elicited coherent bursts of spikes involving two of the four GRNs in each gustatory sensillum. Sugar molecular identity could not be determined using the rate of spiking or bursting of these GRNs alone. Stimulation with sugars of little or no metabolic value generally failed to elicit spikes and did not evoke feeding. Furthermore, toxic sugars inhibited the responses of sugar-sensing GRNs to sucrose. Activation of a third GRN provided information about sugar molecular identity. This GRN spiked selectively to relatively high concentrations of the nectar sugars, fructose, sucrose, and glucose. Our data show that information about sugar metabolic value and identity is encoded by a population of GRNs in each sensillum. This information guides bee feeding behaviour through its effect on the proboscis extension reflex and time in contact with food.

78-3 Pašukonis, A*; Serrano Rojas, SJ; Fischer, MT; Loretto, MC; Shaykevich, D; Rojas, B; Roland, A; Marcillo, A; Ringler, E;

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Ringler, M; Coloma, LA; O'Connell, L; Stanford University, Stanford, Max Planck Institute of Animal Behavior, Radolfzell, University of Jyväskylä, Jyväskylä, INSERM, Toulouse, Centro Jambatu for Research and Conservation of Amphibians, Quito, Bern University, Bern, Centro Jambatu for Research and Conservation of Amphibians , Quito; *apasukonis@stanford.edu*

Do parental roles shape species and sex difference in poison frog space use and navigation?

Species and sex differences in space use and spatial abilities have been well-studied in birds and mammals but remain unexplored in other vertebrates. Poison frogs shuttle tadpoles from terrestrial clutches to scattered pools in the rainforest, but the parental sex roles and parental behaviors differ among closely related species. We tracked three poison frog species with different parental roles in the field to explore the interactions between parental care, reproductive strategy, space-use, and navigational ability. Parental duties of tadpole transport and provisioning increased the movement extent in the care providing sex. The degree of sex difference in the extent of space use and daily mobility varied among species and was influenced by the species-specific reproductive strategy. Observed species differences in space use were also reflected in striking differences of navigational strategy and ability, but navigational sex difference was marked only in one species. Together, our data reveal how a complex interplay between parental roles, reproductive strategy, and movement results in striking species and sex differences in space use and spatial abilities among closely related species.

S5-5 Patel, A*; Jericevich, R; Knemeyer, A; Jusufi, A; University of Cape Town, Max Planck Institute for Intelligent Systems; *amir.patel@uct.ac.za*

Cheetah tail behavior during pursuit

Rapid maneuvers are critical for animal survival in predator-prey interactions and these behaviors are more likely to apply selective pressure on performance, stability and mechanical limits compared to the extensively studied steady-state motion. Maneuvers such as jumping (eg. lemurs, mantises and jumping spiders) or aerial righting (eg. lizards or bats) often introduce instability which need to be actively compensated for. The cheetah (Acinonyx jubatus)

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is not only the fastest terrestrial animal but also one of the most maneuverable. These rapid maneuvers are often accompanied by dramatic swinging of its lengthy tail. However, these tail motions are under-explored. Here, we present an overview of stabilization behaviors for animals maneuvering using wings, limbs, and tails. We show kinematic simulations comparing various stabilization strategies and propose a maneuver template. We also present whole-body kinematic data obtained from captive-bred cheetahs in South Africa during 94 enrichment exercises. We analyzed over 60 tail flicks measured rotations of over 800 deg/s which further imply its use as a stabilizing element.

90-2 Paterniti, MC*; Davis, JE; Radford University; *mpaterniti@radford.edu*

Potential impacts of lithium mining on vulnerable species and ecosystems

As our society moves towards becoming more sustainable, the electric vehicle has become the face of technological advancements and our transition away from fossil fuels. Every electric vehicle is based on a lithium ion battery, as are the batteries in our smart phones and laptops. "By the year 2025, lithium demand is expected to increase to approximately 1.3 million metric tons of LCE (lithium carbonate equivalent) - over five times today's levels" (Forbes, 2019). A large issue within the increase in lithium demand is that there is little to no current research on the environmental effects that lithium mining facilities have on the local ecosystems and wildlife populations that surround them. The impacts of lithium pollution may be most severe if they influence the behaviors or survival of keystone species, those central to the food webs and ecological processes of ecosystems. In this work I used metanalyses and descriptive research to identify species and populations of concern. I began by identifying the top 3 lithium producing countries and the primary mining facilities within them. I then researched the ecosystems surrounding these facilities, with special focus on keystone species that might be most physiological disrupted by lithium impact. Here I present the preliminary results of this survey, with suggestions for future research and a caution towards the unforeseen impacts of mining.

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97-12 Patmore, JM*; Reiss, JO; Humboldt State University; *jmp1347@humboldt.edu*
Morphology of the larval olfactory organ in the Koh Tao Island caecilian (Ichthyophis kohtaoensis)
Caecilians are poorly studied compared to the more familiar amphibians, frogs and salamanders, and this is especially true of the larval stage. In basal members of all three groups, we know that the nasal sac is remodeled considerably during metamorphosis, allowing a transition from aquatic (water) smelling to terrestrial (air) smelling. Yet despite this general similarity, previous work suggests that significant differences exist among larvae of the three groups. Using paraffin embedding and traditional histology, among other methods, we examined the morphology of the larval olfactory organ of the Koh Tao Island caecilian (*Ichthyophis kohtaoensis*). In the caecilian larva the external naris gives way to a short vestibule; this widens into the principal cavity (PC) which continues to widen until about midway through the organ. The vomeronasal organ (VNO) lies ventrolaterally; it also begins midway and runs posteriorly along the ventrolateral PC. As one approaches the choana, the VNO shifts medially and the choanal slime sac (CSS) appears. The PC, the VNO, and the CSS all open posteriorly into the choana, which opens directly into the buccal cavity. As in frog and salamander larvae, backflow is prevented by the presence of a choanal valve. Sensory epithelium is found in most of the PC, and on the ventral side of the VNO, while the remainder of the olfactory organ, including the CSS, contains non-sensory epithelium. Overall, while the olfactory organs of larval frogs, salamanders, and caecilians are shaped quite differently, the composition of the sensory epithelium appears similar. Understanding the ontogeny of the olfactory organ in a basal caecilian like *I. kohtaoensis* will help us to further reconstruct the primitive condition of the olfactory organ of amphibians, and therefore of tetrapods in general.

11-6 Paulis, D; Velosa, A; Zornik, E; Ryba, T; Leininger, E*; New College of Florida, Reed College; *eleininger@ncf.edu*
Sex-specific gene expression in Xenopus laevis laryngeal muscle

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African clawed frogs (*Xenopus*) use species- and sex-specific vocalizations to mediate reproductive behaviors. To generate these vocalizations, *Xenopus* have sexually dimorphic laryngeal morphology and physiology, including differences in laryngeal size and fiber composition. We hypothesized that these sexually dimorphic characteristics may arise from differentially expressed genes within each species of *Xenopus*. Using RNAseq, we analyzed levels of gene expression in *Xenopus laevis* male and female laryngeal muscle (n=5) and found 268 transcripts with expression differences above a 4-fold change and 32 genes with expression differences above a 16-fold change with regard to sex. We then characterized genes of interest using data from sequence alignment and gene ontology databases to reveal molecular function, cellular components, and biological processes related to each gene. Muscle transcriptome analyses can help us relate differences in gene expression to sexually dimorphic physiology in these frogs and more broadly can be applied to future genomic studies. Future work will use cross-species comparisons to examine the molecular basis of species-specific vocalizations and expand our knowledge of neuromuscular networks.

16-7 Paulo, P*; Teófilo, FH; Ferreira, C; Moncrieff, AE; Bandeira, LN; Nuñez-Penichet, C; Bosholn, M; Machado, AF; Peçanha, WT; Hrbek, T; Kaefer, IL; Anciães, M; Instituto Nacional de Pesquisas da Amazônia, Brazil, Louisiana State University, USA, University of Kansas, USA, Universidade Federal do Rio Grande do Sul, Brazil, Universidade Federal do Amazonas, Brazil; *pedropaulofers@gmail.com*
Genetic but not phenotypic differentiation is determined by geographic and climatic distances in the blue-crowned manakin
Investigating parallel roles of geography and environmental heterogeneity in diversification provides insights on how neutral and selective forces drive the evolution of biological systems. Here, we investigate if geographic and climate variation explains either genetic or phenotypic variation, or both, in the range of the Blue-crowned Manakin, a polychromatic bird species broadly distributed in the Neotropics. We tested the hypotheses of Isolation by distance, Isolation by environment, and Isolation by adaptation through an integrative approach using genetic, colorimetric, geographic, and climatic data. Through Multiple

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Matrix Regression with Randomization and Mantel correlation statistics, we tested whether intraspecific genetic or phenotypic diversity associates with variation in geographic and climatic distances among localities. Genetic distances were explained by geographic, climatic, and least environmental cost distances, conforming to predictions from IBD and IBE hypotheses, whereas coloration did not vary significantly with geographical or climatic distances. Genetic and colorimetric distances were not correlated, and spatial autocorrelation in climatic data was low. Our results indicate a combined effect of genetic drift and ecological forces in the diversification at the regional scale, and that both stochastic and deterministic processes may operate at a local level in the evolution of adult male plumage coloration

109-7 Pearson, LE*; Weitzner, EL; Tomanek, L; Liwanag , HEM; California Polytechnic State University; *lepearson@alaska.edu*
Development of thermoregulatory capability in Weddell seal pups
Allocation of energy to thermoregulation greatly contributes to the metabolic cost of endothermy, especially in variable ambient conditions. Weddell seal (*Leptonychotes weddellii*) pups are born in the austral spring in Antarctica, and must survive both on ice and in water, two very different thermal environments. This study examined energetic costs associated with development and thermoregulation in Weddell seal pups. We measured mass-specific metabolic rate in air (MR_A) for 8 pups every 2w, from 1-7 weeks old, and also mass-specific MR in water (MR_W), beginning at 3w. We determined when these two values were equivalent (MR_E), signifying when the two environments had the same metabolic cost. Additionally, we calculated thermal conductance, assessed molt status, and estimated body composition. MR_A declined from 9.98+/-2.5 ml O2 $min^{-1}kg^{-1}$ in 1-week-old pups to 6.65+/-1.31 ml O_2 min^{-1} kg^{-1} at 7-week-olds (mean+/-SD), with a high degree of individual variability. There was a significant effect of age on MR_A ($F_{3,27}$=3.484, p=0.029), such that MR_A was significantly lower at 7w than at 1w (p=0.043). MR_W declined from 3w (12.0+/-3.06 ml O_2 $min^{-1}kg^{-1}$) through 7w (8.18+/-2.29 ml O_2 $min^{-1}kg^{-1}$), but there were no significant differences among age classes. By 5w, MR_E was reduced for all but 2 pups, which suggests development of thermal capabilities between 3 and 5 weeks of age. While absolute MR in air

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followed an allometric relationship with mass and scaled with an exponent of 0.7191 (R^2=0.5571), MR in water was not allometric with mass (R^2=0.0002). Timing of MR_E did not vary with molt status or estimated body composition. Overall, our results indicate Weddell seal pups have developed their thermal capabilities in water by ~5 weeks of age, independent of the amount of lanugo fur or body composition.

79-2 Pedersen, RW*; Liu, EF; Colorado State University, Fort Collins, CO, University of Kansas, Lawrence, KS ; *rachael_pedersen@yahoo.com*

Age dependent search behavior in the Colorado Checkered Whiptail Aspidoscelis neotesselata

Differences in age and body size lead to distinct physiological abilities and needs, which can be reflected in behavioral differences between adults and juveniles. Detailed examination of movement can lend insight into how adults and juveniles vary the priorities of foraging, thermoregulating, and escaping predators. We examined variation in movement and microhabitat use patterns of adult and juvenile Colorado Checkered Whiptail lizards, *Aspidoscelis neotesselata* hypothesizing that movement path measurements and patterns of space use would vary among foraging lizards based on age class. We determined movement paths by conducting 1-h focal observations wherein we followed 30 foraging lizards and marked their position every 30 s. We then measured the distances and angles between each marked location and recorded the microhabitat occupied at each location. Both movement paths and microhabitat use differed between age classes. Adults had longer step lengths (straight-line distances between consecutive positions) and path lengths (sum of all step lengths), using larger areas overall than juveniles. Direction and duration of each movement path segment also differed, with adults making more long, forward movements, while juveniles made more short, lateral moves. Further, age classes differed in their microhabitat use; adults spent more time in mountain mahogany shrubs and open spaces, whereas juveniles more commonly occupied juniper trees, dead wood, and grasses. Movement patterns differed both within and between age classes depending on microhabitat type. Contrasts in movement and microhabitat use likely reflect age-specific differences in

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foraging requirements and abilities, although thermoregulation might also play a role. Further investigations are merited.

63-2 Peng, WX*; de Cuba, AG; de Boer, WF; Matson, KD; Wageningen University, Wageningen; *weixuan.peng@wur.nl*

To what extent do life history characteristics and other ecological traits predict avian immune defences? A systematic review

The immune system is essential for survival and reproduction by animals living in environments full of pathogens and parasites. However, the immune system competes with other physiological functions and behavior for energy and nutrients. In light of such trade-offs, immune defenses in animals are shaped by their broader ecology. In general, immune defenses can be broken into two categories: innate and adaptive. To date, ecological immunologists have emphasized the value of innate defenses over adaptive ones, since the former serve as an organism's first line of defense. Additionally, some innate defenses are relatively consistent over time in the face of environmental changes. Targeting innate humoral immune defenses, the hemolysis-hemagglutination (HLHA) assay has two quantifiable endpoints: lysis (HL), which is a function of complement, and agglutination (HA), which is a function of natural antibodies (NAbs). In our systematic review, we investigated whether life history characteristics and other ecological traits predict HL and HA values in birds. We collected HL and HA values of 108 bird species from all peer-reviewed empirical studies that cite the original methodological publication (from 2005; n=76). We also collected from the literature data on life-history traits (clutch size, body mass, and lifespan), behavioral and ecological factors (food type, social structure, migratory strategy, and habitat type), and annual cycle stages (breeding, migration, or overwintering) of the study populations. Our results contribute to the understanding of the drivers of immunological diversity.

69-4 Pepper, RE*; Riley, EE; Baron, M; Hurot, T; Tor Nielsen, L; Koehl, MAR; Kiørboe, T; Andersen, A; University of Puget Sound, Technical University of Denmark, Ecole Normale Superieure Paris-Saclay, Ecole Polytechnique, University of California

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The effects of external flow on the feeding currents of sessile microorganisms

Microscopic sessile suspension feeders live attached to surfaces and, by consuming bacteria-sized prey and by being consumed, they form an important part of aquatic ecosystems. Their environmental impact is mediated by their feeding rate, which depends on a self-generated feeding current. The feeding rate has been hypothesized to be limited by recirculating eddies that cause the organisms to feed from water that is depleted of food particles. However, those results considered organisms in still water, while ambient flow is often present in their natural habitats. We show, using a point-force model, that even very slow external flow is sufficient to disrupt the eddies around perpendicular suspension feeders, providing a constant supply of food-rich water. However, the feeding rate decreases in external flow at a range of non-perpendicular orientations due to the formation of recirculation structures not seen in still water. We quantify the feeding flow and observe such recirculation experimentally for the common suspension feeder *Vorticella convallaria* in external flows typical of streams and rivers.

46-11 Peralta Martinez, KY*; Trevelline, BK; Martinez-Mota, R; Dearing, MD; Derting, T; Pasch, B; Kohl, KD; University of Pittsburgh, Cornell University, University of Utah, University of Utah, Murray State University, Northern Arizona University; *kyp16@pitt.edu*

Understanding how fiber-induced increases in gut size help to maintain optimal digestion in rodents

Optimal digestion theory has been used to model expected changes in gut structure and function to maintain maximal digestive efficiency (DE) under changing food supply. For instance, DE typically decreases with increasing amounts of indigestible fiber in the diet. However, animals can remodel the gut, often displaying larger and longer GI tracts when on high fiber diets to maintain nutrient uptake as non-digestible materials slowly travel down the gut and encounter greater absorptive surface area. A detailed understanding of how physiological processes across levels of biological organization optimize function remains one of the "Grand

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Challenges" in animal physiology. Here, we studied three closely related rodent species with different feeding strategies, *Microtus montanus* (herbivore), *Peromyscus leucopus* (omnivore), and *Onychomys torridus* (insectivore). We fed individuals four different diets varying in fiber and protein content for five weeks. We observed plastic responses in small intestinal length, cecal mass, and activities of digestive enzymes, though each species exhibited unique increases and decreases in each function. Dry matter digestibility (DMD) and fiber digestibility (FD) also varied across species and as an effect of diet. Finally, we conducted path analysis to integrate our data and understand what physiological changes underly the variability in DMD and FD. Path analysis supported our idea that fiber is a main driver of plasticity followed by internal cellular processes. These data will enhance our understanding of optimal digestion theory and identify physiological changes that are most important for maximizing digestive performance.

S9-8 Perelmuter, JT*; Sisneros, JA; Forlano, PM; Cornell University, University of Washington, Brooklyn College; *jp2469@cornell.edu*

Dopamine seasonally modulates adaptive sensitivity of the inner ear for reproductive communication in a vocal fish

The plainfin midshipman fish, *Porichthys notatus*, relies upon the production and reception of social acoustic signals to coordinate seasonal reproduction. As fish migrate to the intertidal zone in the summer, males establish rocky nests and produce nocturnal courtship calls. Females locate males for spawning based on this advertisement signal and, coincident with the breeding season, undergo a dramatic, hormonally regulated enhancement of peripheral auditory function which facilitates mate detection. Our recent work indicates that dopamine is an important contributor to this seasonal plasticity. Summer females in reproductive condition have reduced dopamine innervation of the saccule, the primary end organ for acoustic transduction in midshipman. Serial TEM analyses confirm reduced potential for dopaminergic release in the saccule during the breeding season. Dopaminergic boutons are smaller, fewer in number and less likely to directly contact hair cells in summer reproductive females as compared to winter, non-reproductive

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females. Exogenous dopamine and receptor-specific drugs applied to the saccule during sound-evoked recordings reveal that dopamine increases auditory thresholds via a D2-like receptor. Summer females express lower D2a levels than winter, non-reproductive females and D2a expression is negatively correlated with individual acoustic sensitivity, regardless of reproductive state. Altogether, these findings suggest that reduced dopaminergic innervation in the saccule, likely initiated by a seasonal change in circulating steroids, provides a release of inhibition, adaptively improving auditory sensitivity for mate localization. Adjusting the level of dopaminergic modulation in the peripheral auditory system may be a mechanism by which other vertebrate species modulate auditory sensitivity during critical periods of social interaction.

21-5 Perez, A*; Gabor, C; Aspbury, A; Texas State University ; *abrahamlperez52@gmail.com*

Urbanization affects individual behavior and cognition in Gambusa affinis

Urbanization, as indicated by increased impervious cover, alters freshwater communities via factors associated with urban stream syndrome. We hypothesized that livebearing Western mosquitofish, *Gambusa affinis*, from populations varying in levels of urbanization would differ in behavior and cognitive performance. Urbanization of six streams was determined by the percent of impervious cover, agricultural development, and underdeveloped land within the surrounding watershed. This species is tolerant and native but found invasive world-wide. Female fish were collected from the streams and acclimated in the lab and then were placed individually in holding containers within a larger arena for behavioral observation. We recorded the individual's boldness, exploration, and latency to leave the enclosure. We then placed fish in a separate container in groups of 4 to record shoaling behavior. For cognitive performance we tested individual females using a detour test design with a motivation fish held at the opposite end in a transparent container. We measured problem solving and motivation to reach the other female behind a clear barrier in this maze. Individuals that explore more or faster may have higher cognitive skills. The fish from the population with an intermediate level (21%) of urbanization were less likely to emerge

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and decreased motivation compared to the other populations. The fish from the least urbanized population (2%) shoaled the most. Our results indicate that urbanization affects fish motivation and cognitive behaviors in a non-linear fashion.

108-5 Perez-Galvez, FR*; Awde, D; McCabe, EA; Teets, NM; University of Kentucky; *frpe222@uky.edu*

Computer assisted analysis to improve throughput and precision of knockdown time assays

Knockdown-time assays, which are often used to assess physiological injury from stress exposure, typically rely on human observation to determine the end of biological activity. Increased throughput and reliability of these classic assays is needed to improve large-scale phenotypic screens of stress tolerance for species comparisons and genomic association studies, but the impact of observer bias on measurement uncertainty and treatment effect estimates has not been systematically tested. Here, we develop a novel computer algorithm to automatically analyze video files from time-to-knockdown assays, and we compare this method against human-derived estimates. Adult *Drosophila melanogaster* were held at constant high temperatures and video-recorded until movement ceased, and video-frames were converted to a pixel change rate. We then developed custom Python scripts to test several algorithms for estimating knockdown time and matching the human interpretation. The computational methods had reduced standard deviations relative to human-derived measurements, indicating our new method improves precision. Rank order and significant differences between experimental groups were generally consistent among methods, but computer-generated estimates of knockdown time tended to be shorter. Taken together, these results indicate that computer-assisted video analysis of time-to-knockdown assays can reduce measurement error and increase throughput, which can be beneficial for applications such as genetic association studies or niche-modelling.

S1-6 Perkin, EK*; Wilson, MJ; Hatfield Consultants, Susquehanna University; *lizperkin@gmail.com*

Light waters: How anthropogenic light alters river ecosystems

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Due to the human propensity to build cities near freshwater, river ecosystems are disproportionally exposed to artificial light at night (ALAN) compared to other ecosystems. Benthic invertebrates play a critical role in lotic ecosystems, as they are an important food source for fish and birds, as well as maintain water quality. Because they are more active at night, when the chance for detection by visual predators is low, one may expect benthic invertebrate activity to decrease under exposure to ALAN. However, studies on benthic invertebrate activity under ALAN have shown mixed responses. One potential explanation for these contradictory results is adaptation or acclimation to ALAN. I will present results from a recent study of benthic invertebrate activity across an ALAN gradient, and will discuss its implications for stream ecosystems as a whole.

41-11 Perry, O*; Zornik, E; Reed College; *ezornik@reed.edu*
Crescent Loom: Weaving and unravelling biophysical motor circuits in an online learning activity

Crescent Loom is a video game that wraps a biophysical neural simulation in an easy-to-use interface where players design the body and brain of a creature in order to navigate 2D underwater levels. With the onset of the COVID-19 pandemic, there has been a heightened need for neural circuit simulators for use in remote learning in addition to the ongoing need for high-quality engaging neural simulation and visualization software. Therefore, we have adapted Crescent Loom to serve as an in-silico lab that supports active inquiry-based learning for neurobiology students and can be run from inside a web browser. Neurons are simulated using a resistor-capacitor compartmental model, showing in real time both passive and active current spreading within neurons as well as the state of ion channels within each section of membrane. Players can simultaneously see the activity of neurons in motor circuits and the behavior of the swimming animal. We've modified the game for use in remote experimental investigations. Students are given a circuit with obscured connectivity and the tools to do experiments (e.g. blocking neurotransmitters, stimulating specific neurons) while recording from neurons in order to generate a prospective connectivity map. These experiments allow students to observe how experimental manipulations affect behavior, and to identify the

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cellular and network basis for the observed changes. Using the in-game editor, both educators and students can create and upload their own creatures for use in the activity. Our aim with Crescent Loom is to equip educators with an accessible, flexible, free, and high-quality tool to meet the challenge of teaching neurobiology remotely.

80-7 Petersen, JC*; Eng, CM; Marsh, RL; Azizi, E; Roberts, TJ; Brown University, Providence RI, University of California, Irvine; *jarrod_petersen@brown.edu*

Architectural elasticity in pennate muscle

Muscle contractile elements operate in series with elastic structures that influence performance. A crucial tool in characterizing these elastic structures and their behavior has been the quick-release experiment. When an isolated muscle experiences a very rapid change in length, the associated change in force characterizes elastic behavior, as long as the motion occurs at time scales shorter than required for cross-bridge cycling. Series elasticity can influence muscle shortening, but muscles also undergo three-dimensional shape changes during contraction. To determine whether elastic elements contribute to these shape changes we designed a quick-release experiment to quantify the relationship between force and length in the transverse (orthogonal to the line of action) direction. A pennate muscle, bullfrog flexor digitorum superficialis brevis, was attached to a servomotor and implanted with markers to track fiber length, muscle length, fiber pennation angle and thickness. A control signal was used to quickly drop the regulated force of the servomotor mid-way through a contraction. Dimensional changes were tracked by video at 500 fps and force was measured by the servomotor. Our results show that a quick drop in force is associated with a bulging of muscle thickness and a reorientation of fibers to a higher angle of pennation. These observations, reproducible by a simple mathematical and physical model, are consistent with the idea that muscle bulging during contraction is modulated by force through the elastic behavior of the extracellular matrix. This architectural spring may store elastic energy to contribute to power output during animal movement.

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S9-9 Petersen , CL; Hurley, LM*; University of Minnesota Twin Cities, Indiana University; *lhurley@indiana.edu*

Neuromodulatory feedback to sensory systems: how serotonin conveys contextual information to the auditory midbrain

Context is an important source of information that allows animals to appropriately respond to social signals. In a mouse model of vocal communication, broadly defined aspects of context such as the identity of social partners, internal state, and prior social experience converge to influence how the serotonergic system interacts with auditory brain regions. Serotonin may therefore be one source of contextual information in the auditory system, but the functional consequences of this interaction have not been well-explored. To further understand the functional anatomy of auditory-projecting serotonergic neurons, tract tracers were injected into the inferior colliculus (IC) in the auditory midbrain. The dorsal raphe nucleus (DRN) was then imaged in conjunction with immunohistochemistry for a synthetic enzyme for serotonin, tryptophan hydroxylase (TPH), and for the immediate early gene c-Fos. Males and females were compared following interaction with a member of the opposite sex, or confinement in a small area. Neurons double-labeled for tract tracer and TPH were found in two distinct subregions of the DRN. Males had a higher number of double-labeled neurons than females, suggesting a sexually dimorphic serotonergic projection to the auditory midbrain. Further, we found that the number of TPH/c-Fos positive neurons were correlated with behavior during social interaction in females, but not males. The direction of the correlation was opposite within different DRN subregions, suggesting that activity in DRN subregions may vary across social context.

3-4 Peterson, AN*; McHenry, MJ; Univ. of California, Irvine; *anpeter1@uci.edu*

For slow red lionfish, persistence and distance matter when pursuing fast prey

A diversity of predators succeed in overcoming prey with a high-speed pursuit or a high-acceleration strike during an ambush. However, many predatory fishes approach evasive prey at relatively

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slow speed. One such example is the red lionfish (*Pterois volitans*). A slow and highly decorated suction feeder, red lionfish successfully stalk evasive prey and have earned a reputation as a formidable and widely invasive predator in the western Atlantic Ocean. To understand the strategy of such slow predators, we performed kinematic measurements of individual red lionfish as they pursued green chromis (*Chromis viridis*). Despite moving half as fast as their prey, red lionfish successfully captured the chromis in 62% of our experiments, which were performed in a cylindrical arena (1.4 m diameter) for up to one hour. The red lionfish ceaselessly pursued chromis, which avoided the predator with routine swimming. By analyzing the trajectories of predator and prey, we found that red lionfish employed a pure-pursuit strategy, with a heading that was consistently directed toward the prey's position. The red lionfish did not attempt a predatory strike until the rare instant when prey permitted a close approach (<10 cm). At this distance, red lionfish rarely chose not to strike (<16%) and were usually successful (74% of strikes) in capturing the prey. Prey orientation and fish speed had little influence on a strike or capture. Therefore, the slow red lionfish employs a persistent pure-pursuit strategy that succeeds through chance events when a prey fails to maintain avoidance swimming and falls within striking distance. This persistent strategy may be common in fishes and other animals that pursue faster and more maneuverable prey.

88-9 Pettersen, AK*; Cornwallis, CK; Uller, T; Feiner, N; Noble, DWA; While, GM; Lund University, The Australian National University, University of Tasmania; *amanda.pettersen@biol.lu.se*

Behavioural adaptations in egg laying ancestors facilitate evolutionary transitions to live birth

Live birth is an evolutionary innovation that has enabled reptiles to colonise environments that are normally hostile for developing embryos. While the benefits of live bearing are undisputed, transitions from egg laying to live birth should be constrained since adult lizards and snakes typically have preferred body temperatures that exceed the upper lethal limit of embryos. However, live birth has evolved many times in lizards and snakes. Phylogenetic comparative analyses of 224 species revealed that transitions to live birth occur despite significant mismatches

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between the maternal and offspring thermal optima. We show that such mismatches are resolved by gravid females down-regulating their body temperature towards the thermal optimum of developing embryos. Importantly, this thermoregulatory behaviour evolved in ancestral egg laying species long before the evolutionary emergence of live bearing. Transitions to live bearing are then frequently followed by a reduction in preferred female body temperature that further eliminates conflicts over thermal optima between adults and embryos. In many of these lineages, females elevate their temperature when gravid - a behaviour that results in earlier birth and thus promotes offspring fitness. Maternal thermoregulatory behaviour therefore bypasses the constraints imposed by a slowly evolving thermal physiology and is likely to have been a key requirement for the repeated transitions to live birth across reptiles.

36-7 Pevsner, SK*; Grossnickle, DM; Luo, Z-X; University of Bristol, University of Washington, University of Chicago; *skpevsner@gmail.com*

Forelimb functional diversity in Didelphimorphia and Diprotodontia is not strongly limited by developmental constraints

Marsupials show less diverse locomotor strategies than placentals. A common hypothesis for this discrepancy is that forelimb morphology is developmentally constrained in marsupial neonates due to the forelimb crawl from the birth canal to the pouch of the newborns. This would limit forelimb disparity and locomotor strategies more so in marsupials than in placentals. This developmental constraint hypothesis predicts that the less disparate forelimbs are less well correlated with the overall ecomorphological diversity than hindlimbs; forelimbs are less adapted to ecomorphologies than hindlimbs that are not involved in the neonatal crawl in marsupials. To test this prediction, we built a large dataset of limb skeletal metrics of major groups and all ecomorphotypes of marsupials, and we applied linear discriminant analyses and phylogenetic MANOVAs. Contrary to the predictions of the forelimb constraint hypothesis, didelphimorphian and diprotodontian forelimb morphology is often a better or equally good predictor of locomotor strategy than hindlimb morphology. Further, we show that this forelimb vs hindlimb difference can vary

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in additional marsupial groups (e.g., dasyuromorphians), in which hindlimbs are considerably better predictors of locomotor strategies as expected by developmental constraint hypothesis. These results suggest that developmental constraints on forelimbs, if present, are counter-balanced and can be overcome by selection associated with ecological traits in didelphimorphians and diprotodontians. On a macroevolutionary scale, the outcomes of the developmental constraint on forelimbs and ecological adaptation of both limbs can vary in different clades.

72-2 Pfeiffenberger, JA*; Anderson, EJ; Tytell, ED; Tufts University, Medford, MA, Grove City College, Grove City, PA; *jpfeiff2@gmail.com*

Free swimming kinematics and whole-body mechanics of the Atlantic mackerel, Scomber scombrus

Propulsive forces generated by fish are the result of complex interactions between the water and the fish as the fish bends its body back and forth, as well as the interactions of the various materials that make up the body of the fish. While we have a relatively good understanding of body kinematics during swimming, the internal body mechanics of fish during swimming are not fully understood. In this study we collected free swimming kinematics and whole-body mechanical data from the same fish to directly compare individual swimming performance with internal body mechanics. We measured tail beat amplitude and body waveform for Atlantic mackerel (*Scomber scombrus*) as they swam in a flow tank over speeds from 0.2 to 1 m/s. We then measured the body stiffness using a custom bending rig. Animals were pithed and mounted on a custom built, oscillatory bending apparatus that bent the body back and forth at preset amplitudes (5°) and frequencies (2 - 10Hz) to measure whole-body mechanics. We hypothesized that mackerel would differ in their body mechanics and that these mechanical differences would contribute to individual differences in preferred swimming kinematics. Specifically, individual fish with more flexible bodies would use higher tail beat amplitudes as well as lower frequencies at higher velocities. We found that the preferred tail beat amplitude of swimming at 2 BL/s was negatively correlated with flexural stiffness (EI). Additionally, the tail beat frequency of swimming was weakly negatively correlated with EI. These

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preliminary results show that individual fish differ in their mechanical properties, and that these mechanical differences may contribute to differences in swimming kinematics and ultimately to performance.

48-5 Phillips, JG*; Linscott, TM; Rankin, AR; Kraemer, AC; Shoobs, NF; Parent, CE; University of Idaho; *jphillips@uidaho.edu*
Archipelago-wide patterns of colonization and speciation among an endemic radiation of Galápagos land snails
Newly arrived species on young or remote islands are likely to encounter less predation and competition than source populations on continental landmasses.The associated ecological release might facilitate divergence and speciation as colonizing lineages fill previously unoccupied niche space. Characterizing the sequence and timing of colonization on islands represents the first step in determining the relative contributions of geographical isolation and ecological factors in lineage diversification. Herein, we use genome-scale data to estimate timing of colonization in Naesiotus snails to the Galápagos islands from mainland South America. We test inter-island patterns of colonization and within-island radiations to understand their contribution to community assembly. Partly contradicting previously published topologies, phylogenetic reconstructions suggest that most Naesiotus species form island-specific clades, with within-island speciation dominating cladogenesis. Galápagos Naesiotus also adhere to the island progression rule, with colonization proceeding from old to young islands and within-island diversification occurring earlier on older islands. Our work provides a framework for evaluating the contribution of colonization and in situ speciation to the diversity of other Galápagos lineages.

83-5 Picinic, BN*; Paluzzi, JP; Donini, A; York University; *britneyp@my.yorku.ca*
Effects of diet on aquaporin abundance in the disease-vector mosquito, Aedes aegypti
The mosquito, Aedes aegypti, is found in tropical and sub-tropical regions of the world and is a vector for arboviral diseases such as Dengue, chikungunya, and Zika. The adults of this species are

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terrestrial while the larvae are aquatic, thus they face different challenges to the maintenance of appropriate salt and water levels in body fluids (osmoregulation). Female adult A. aegypti require a blood meal to obtain the necessary proteins and amino acids for egg development. Upon engorging a blood meal, the female must deal with incoming water from the blood plasma, while also absorbing essential nutrients from the blood proteins. Osmoregulation involves the water and ion-flux across the epithelia of osmoregulatory organs and in A. aegypti these include the midgut, Malpighian tubules, and hindgut. The transport of water across the epithelial tissue involves transmembrane proteins known as aquaporins (AQPs), which function as selective channels to facilitate the movement of water. Due to the effects of feeding in A. aegypti, including but not limited to excess water, it has been hypothesized that the AQP abundance is affected by the intake and digestion of the blood meal for females and by sugar feeding for both males and females. In this study AQP1, 2, 4, 5, and 6 have been localized in the adult female and male A. aegypti using immunohistochemistry. Immunolocalization of the AQPs has identified that a blood meal may increase the abundance of select AQPs in the Malpighian tubules and fat body of females. However, AQP1 abundance assessed using Western blot analysis in the female Malpighian tubules demonstrates that there is a significant decrease in protein abundance 24hr post blood meal. Western blot analysis for protein abundance of other AQPs is the subject of continuing work.

4-3 Pierce, CJ*; Sun, G; Lu, H; Goldman, DI; Georgia Institute of Technology; *cpierce43@gatech.edu*

Laboratory studies of burrowing locomotion in nematodes

Despite being one of the most well studied model organisms in biology, little is known about the locomotion of *C. elegans* in naturalistic settings. Ecological literature suggests that these animals contend with heterogenous environments like rotten fruit, soil and even the backs of insects; in contrast, the majority of behavioral studies of *C. elegans* are conducted in homogeneous Newtonian fluids or on the surface of agarose gels, where worms typically crawl forward via regular, undulating waves of body curvature. Using 3D, stereo-microscopy techniques, we image *C. elegans* burrowing in gel environments with tunable viscosities and

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bulk moduli, models of conditions in rotting fruit. Previous studies in fluids find that body undulation wavelengths and frequencies decrease with increasing resistance (increasing viscosity). In highly resistive non-Newtonian environments imposed by gels, this trend persists, however the motion displays complex, irregular undulatory patterns. Furthermore, kinematic differences in surface crawling and burrowing resemble those of the desert dwelling Shovel nosed snake (*C. occipitalis*) atop or within dry granular media. In both organisms, principal component analysis reveals a behavior well-captured by a small number of quasi-sinusoidal components, however the amplitude variation of these components in the burrowing case displays a much higher degree of complexity, accounting for the qualitative differences in body shape. We conjecture that burrowing introduces a distinct neuromechanical regime, likely arising from physiological constraints on power or force production by the muscles. Finally, our experiments reveal new complex turning behaviors featuring dramatic body bends and multiple self-intersections seldom observed in other conditions.

54-2 Pinion, AK*; Cohen, KE; Donatelli, CM; Kruppert, S; Summers, AP; Texas A&M University, College Station, TX, USA, Friday Harbor Labs, University of Washington, Friday Harbor, WA, USA, Department of Biology, University of Ottawa, Ontario, Canada; *Akpinion@tamu.edu*

Come and spaghett It: Morphology and feeding of the quillfish, Ptilichthys goodei

Ptilichthys goodei is a filiform member of the Zoarcoidei easily recognized by its exceptional elongation, protuberance on the lower jaw, and a thread-like filament trailing from the caudal fin. Little is known about the life history, behavior and morphology of the quillfish because the species is rarely collected. We investigated the skeletal and soft anatomy, including the composition of the protuberance of the lower jaw and caudal filament. We used high speed video to film feeding events from a single quillfish and locomotion of several individuals. We used SEM, histology, and computed tomography scans of quillfish to describe morphology. Quillfish teeth are thecodont, deeply socketed into bone and have a robust layer of enamel and dentine. The

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protuberance on the lower jaw is narrow and ridge-like, free of taste buds, and composed of dense and loose connective tissues. The function of this structure remains mysterious, though we hypothesize that it plays a role in the burrowing behavior documented in the adults. Feeding is accomplished by suction and preceded by a very slow preparatory phase in which the fish contorts into a characteristic arch before explosively darting forward, opening its mouth, and sucking in the prey suggesting elastic energy storage plays a role in capture. Locomotion is unusual for an elongate fish both because there is no visible wobble using undulation and little slippage. All data are from small animals, less than ⅓ of maximum size. We know of no source for adult animals, but our successful month-long captivity of one individual raises the possibility of captive rearing.

S8-5 Piorkowski, D; Tunghai University, Taichung, Taiwan; *piorkowski@thu.edu.tw*

The hidden roles of silk fibers during adhesion in arthropod capture threads

Some predatory arthropods use adhesive capture threads to arrest prey in traps. These capture threads are composites with two primary components: underlying silk fibers surrounded by an adhesive material - an aqueous glue or sticky nanofibrils. The silk fibers in these systems were once thought to primarily suspend the adhesive component with little or no active role in adhesion. However, studies of glue-coated viscid threads used by orb webs spider found that the compliant underlying fibers can perform up to 50% of the work of adhesion as forces are effectively transferred from the glue. To determine if other arthropod capture threads operate as similarly integrated systems, the effects of mechanical plasticization and hidden-length were tested on the glue-coated fishing lines of *Arachnocampa tasmaniensis* glowworms and spider cribellate silk - threads using 'dry adhering' nanofibrils rather than glue. In capture threads of glowworms and the cribellate spider *Hickmania troglodytes*, silk fibers are mechanically plasticized by the atmospheric water of the wet environments these animals inhabit. This allows transfer of adhesive forces to the more compliant silk fiber and improves work of adhesion. In at least 23 spider families that use cribellate threads, *H.*

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troglodytes being an exception, hidden length is present in the form of coiled fibers that confer extreme extensibility of 500-1400%. Experimental cutting of coiled fibers or behavioral manipulation during production that reduces coiled fiber length dramatically reduces thread extensibility and work to fracture, which leads to decreased work of adhesion. Increased compliance of silk fibers through structural or material properties leading to improved adhesive performance may represent an emerging principle in how these threads operate as prey-capture devices.

26-11 Piotrowski , ER*; Tift , MS; Crocker , DE; Khudyakov, JI; University of the Pacific, Stockton, CA, University of North Carolina, Wilmington, Sonoma State University, Rohnert Park, CA, University of the Pacific, Stockton, CA ; *epiotrowski@pacific.edu*

Expression of markers associated with carbon monoxide signaling in a deep-diving mammal

Deep-diving mammals routinely experience hypoxia and ischemia-reperfusion as part of their life history. Adaptations to diving include increased blood oxygen stores and high antioxidant capacity. In addition, marine mammals produce high levels of endogenous carbon monoxide (CO), which has been shown in laboratory systems to protect cells and tissues from damage caused by ischemia-reperfusion. Northern elephant seals, one of the deepest diving pinnipeds, produce and maintain CO at concentrations higher than those of human cigarette smokers, and thus provide a natural study system for examining the role of CO in hypoxia tolerant mammals. The primary source of endogenous CO production occurs from the breakdown of heme by heme oxygenase enzymes. Levels of endogenous CO and heme stores are also known to increase with age in elephant seals. We measured the expression of heme oxygenase genes (*HMOX1* and *HMOX2*) and other genes associated with CO signaling (*BVR*, *NRF2*, *GPX3*, *PGC1A*, *ESRRA*) in skeletal muscle and blood of northern elephant seals of various age classes (weaned pup, juvenile, and adult). We found that the expression of *HMOX1* and *HMOX2* genes increased with age and was significantly correlated with the expression of genes associated with mitochondrial biogenesis (*ESRRA*) and antioxidant defense (*GPX3*, *NRF2*; $p < 0.05$). These data suggest that increased heme oxygenase expression may underlie high CO production, antioxidant

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expression, and diving capacity in adult seals, providing insights into cellular mechanisms underpinning hypoxia and ischemia-reperfusion tolerance in deep-diving mammals.

2-7 Plachetzki, DC*; Pankey, MS; MacManes, MD; Lesser, ML; Walker, CW; University of New Hampshire; *david.plachetzki@unh.edu*

The bilaterian ancestor possessed a complex apoptosis genetic toolkit that was subsequently dismantled in ecdysozoans but preserved in lophotrochozoans and deuterostomes

Apoptosis is a fundamental feature of multicellular animals and is best understood in mammals, flies, and nematodes, with the invertebrate models being thought to represent a condition of ancestral simplicity. However, the existence of a leukemia-like cancer in the softshell clam *Mya arenaria* provides an opportunity to re-evaluate the evolution of the genetic machinery of apoptosis. Here we report the whole genome sequence for *M. arenaria* which we leverage with existing data to test evolutionary hypotheses on the origins of apoptosis in animals. We show that the ancestral bilaterian p53 locus, a master regulator of apoptosis, possessed a complex domain structure, in contrast to that of extant ecdysozoan p53s. Further, ecdysozoan taxa, but not chordates or lophotrochozoans show a widespread reduction in apoptosis gene copy number. Finally, phylogenetic exploration of apoptosis gene copy number reveals a striking linkage with p53 domain complexity across species. Our results challenge the current understanding of the evolution of apoptosis and highlight the ancestral complexity of the bilaterian apoptotic tool kit and its subsequent dismantlement during the ecdysozoan radiation.

58-2 Pollock, HS*; Hauber, ME; Strejc, B; Tarwater, CE; UIUC, University of Wyoming; *henry.s.pollock@gmail.com*

Follow the fracas: Global patterns of variation in disturbance foraging behavior of birds

Environmental disturbances influence the distribution of species across space and time, with important implications for community structure and patterns of biodiversity. For example, both abiotic (e.g. fire) and biotic (e.g. army-ants) short-term disturbances flush concealed prey, providing important food resources to

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attending species. Disturbance foraging is widespread across diverse animal taxa, yet we currently lack a systematic understanding of how the behavior varies ecologically, geographically, and taxonomically on a global scale. Here, we conducted a systematic literature review (n = 118 studies, 976 observations) of disturbance foraging behavior among birds (class Aves). We documented disturbance foraging in at least 375 (~4%) species representing 29% (73) of all avian families and 56% (23) of all avian orders. The primary sources of disturbance were biotic, namely terrestrial mammals (principally the orders Primates and Artiodactyla; ~40% of all observations) and arthropods (principally army-ants; ~40%), followed by birds (~11%) and aquatic mammals (~6%). The behavior was most common in forest bird species (>50% of all observations), followed by savanna/grassland species (~16%) and marine/coastal species (~11%). Geographically, the behavior was much more prevalent in tropical regions, with more than 90% of all observations occurring in the Neotropics (~50% of all observations) and the Afrotropics (~40%). Our findings represent the first global synthesis of disturbance foraging in birds and confirm its prevalence across the avian tree of life. Even so, disturbance foraging associations, especially obligate foraging relationships, were most common in tropical forests, providing support for the longstanding hypothesis that ecological specialization is greater in the tropics.

28-7 Pomponi, SA*; Hanisak, MD; Reed, JK; Wright, AE; Harbor Branch Oceanographic Institute - Florida Atlantic University; *spomponi@fau.edu*

The HBOI-FAU marine biotechnology reference collection: a new web-based resource for research

The Marine Biotechnology Reference Collection (MBRC) at HBOI-FAU is a unique collection of more than 30,000 marine specimens from at least 13 phyla. Although the collections were focused on accessing biodiversity for marine natural products research, these efforts resulted in a taxonomically and geographically diverse collection of benthic marine invertebrates and macroalgae. Recognizing the need to have appropriate voucher specimens to identify the organisms from which bioactive molecules were derived, an extensive taxonomic reference collection was established. Collections are

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documented with field notes, photos, videos, and taxonomic vouchers. The MBRC is unique among marine specimen collections: nearly 30% of the specimens were selectively collected with the *Johnson-Sea-Link* submersibles at depths from 150 to 914 m, at locations that are difficult to access due to geography and habitat. Many of the deep-water species have never been photographed *in situ* previously, so the archives provide a unique resource for new species descriptions. There are representatives of the same species collected from different locations and depths for more than 30 years, providing an opportunity to study changes over time and under different environmental conditions. To secure and improve access to this specimen-based, vouchered, and well-documented natural history collection, a web-accessible database has been created to serve a broad community of biological researchers. Digitizing biological collections and publishing them on the web greatly expands the availability and impact of the collection beyond the scope of a project-based repository. The data will be made publicly available through the HBOI-FAU website and through iDigBio.

9-7 Popecki, MS*; Wares, JP; Stanger-Hall, KF; University of Georgia; *mp52226@uga.edu*

The evolution of pigment diversity in fireflies

There is astounding functional diversity of pigments across insects. Fireflies (Coleoptera: Lampyridae), exhibit variation in body coloration and bioluminescence, yet the evolution of pigments remains unknown in this group. Using a comparative genomics approach, we investigated putative gene duplication events of pigment enzyme and transporter genes in the biosynthesis pathways of two pigment classes. To determine if duplicated genes are adaptive, we tested for selection in *Photinus pyralis*, a firefly species with aposematic coloration and yellow-shifted light emissions. As duplicates may gain divergent function, we assessed expression level of duplicates between sexes and developmental stages in the light producing organ of *Photinus* species. Future work will aim to address patterns of expression across various species and additional tissue types.

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52-4 Porto, A*; Rolfe, SM; Maga, AM; Center for Development Biology and Regenerative Medicine, Seattle Children's Research Institute, Seattle, WA, Friday Harbor Laboratories, University of Washington, San Juan Island, WA, Division of Craniofacial Medicine, Department of Pediatrics, University of Washington, Seattle, WA; *agporto@gmail.com*

ALPACA: a new and general framework for automated landmarking of 3D biological structures

Geometric morphometrics has become an essential tool for the quantitative characterization of complex phenotypes. In the past 20 years, morphometric approaches have been used to study phenotypic plasticity, to test different models of quantitative trait evolution, to infer modularity and integration, to study changes in ontogenetic development, among others. Consequently, morphometric research has undergone rapid development from an analytical standpoint.Despite these developments, the gold standard for landmark data collection has remained largely the same. Morphometric data is, by and large, manually digitized by experts. Manual digitization of landmarks is, however, both low-throughput and subject to a significant amount of inter-observer bias, representing, therefore, an important barrier to further advances in the field.In this talk, I will describe a new and general framework for automated landmarking of 3D biological structures called ALPACA (Automated Landmarking through Pointcloud Alignment and Correspondence Analysis). ALPACA approaches the problem of automated landmarking using deformable pointcloud registration. In short, a reference mesh (the source mesh) is subsampled, aligned and posteriorly deformed to match a target mesh. Using the transformation parameters used to deform one mesh into another, we project the landmark positions of the source mesh into the target one. Given the recent explosion in the availability of 3D datasets in ecology and evolutionary biology, we expect this method to have broad appeal to researchers in the field.

55-7 Pos, KM*; Kolmann, MA; Donatelli, C; Cohen, KE; Egan, J; Hernandez, LP; George Washington University, University of Michigan, University of Ottawa, University of Washington, Friday Harbor Laboratories, Western Michigan University; *kmpos@gwmail.gwu.edu*

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The Gizzard of Oz: mucus and motors and grit, oh my!: A comparative look at gizzards in fishes

Fishes are known for their strange teeth on both pharyngeal and oral jaws, but many fishes are edentulous. Edentulous animals use specialized gastrointestinal anatomy for mechanical and chemical breakdown of food. Birds and some fishes eat biomechanically demanding prey (e.g. plants) and dismantle tough foods through a grinding mill in the gut, the gizzard. This region of the gut is composed of thick, multi-layered muscle and is filled with mucus and grit. While all birds have this organ, our understanding of the morphology, function, and presence of gizzards in fishes remains unclear. Moreover, the differentiation between gizzards and stomachs in fishes has not been established. We use PTA staining, micro-CT scans, particle-size analysis, and histology to describe variation in gizzard morphology across several lineages to elaborate on potential functions. Food particles dissected from the anterior digestive tract (esophagus and gizzard) compared to food particles found in the intestine decrease substantially in species with gizzards. The size of food particles from species without gizzards remains consistent throughout the length of the gut. We used these morphological data to design a motorized gizzard to assess the roles of grit and mucus during food processing; we found that grit composed of both sand and small pebbles was most effective for breakdown of food. We show the importance of a grit-filled gizzard for pulverizing prey in fishes and use our morphological descriptions to better differentiate between a stomach and a gizzard among fishes.

19-12 Potdar, S*; Westerman, E L; University of Arkansas, Dept of Biological Sciences, 850 W. Dickson St. Fayetteville 72701 USA; *sdpotdar@uark.edu*

Toxic, unpalatable and aposematic butterflies respond to specialist predatory bird calls

Many animals are under tremendous predation pressures and have evolved various anti-predatory strategies, such as aposmatic signaling and anti-predator behavior, to decrease predation. These strategies increase an animals' fitness by allowing them to survive and reproduce. However, studies on anti-predatory behaviors have largely focused on organisms that are palatable. Studies on whether

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toxic species that possess aposematic coloration exhibit additional behavioral avoidance of predators, are largely lacking. *Heliconius* butterflies are toxic, unpalatable, aposematic, exhibit roosting behavior, and form Mullerian mimicry rings to avoid bird predation. However, specialized bird predators like Rufous-tailed Jacamar and Eastern Kingbird often feed on these butterflies, decreasing the efficiency of their unpalatability. Previous studies have identified auditory organs in *Heliconius* butterflies, but the functional significance of these organs are not known. We hypothesized that *Heliconius* butterflies may alter their behavior after hearing the calls of their avian predators. We used focal sampling to observe behaviors of *Heliconius melpomene plessini* in response to predatory bird calls and compared it with behavioral responses to control bird call (Toco toucan) and white noise. We found that *H. m. plessini* males and females changed their behavior in response to Jacamar calls only. Males flew longer while females fluttered more in response to Jacamar calls. Both these behaviors have been associated with anti-predatory behavioral strategies in other butterflies. These might be anti-predatory behaviors in *Heliconius* butterflies as well. These results will advance our knowledge in behavioral ecology of toxic and aposematic species.

109-6 Powers, DR*; Lapsansky, AB; Tobalske, BW; George Fox University, Newberg, OR, University of Montana, Missoula, MT; *dpowers@georgefox.edu*

Physiological and behavioral flexibility in heat budget-management during hovering in hummingbirds

The energetic cost of hovering in hummingbirds exceeds 10X BMR. During hovering hummingbirds produce excess metabolic heat due to low mechanical efficiency of their flight muscles . Plumage restricts heat dissipation during hovering so hummingbirds rely on heat dissipation areas where feathers are in low density to eliminate body heat. When temperatures are high gradients for passive heat dissipation are eliminated and hummingbirds can only use short hovering bouts to remain active. Because hummingbirds balance energy budgets over short time periods remaining active throughout the day is critical. In this study we used infrared thermography, open-flow respirometry, and behavioral tracking to

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understand strategies calliope hummingbirds (*Selasphorus calliope*) use to manage heat budgets during hovering over a range of temperatures (5, 22, and 32 ° C). At 32 ° C hovering metabolic rate was higher and bouts shorter than at 5 and 22 ° C. Hummingbirds heated their bill and feet at 32 ° C to above ambient temperature compensating for the reduced thermal gradient. Bills and feet were not heated at 5 ° C to reduce heat loss. Total time flying increased with T_a in spite of a higher thermal load suggesting that induced airflow during hovering plays a role in dissipating heat. At 5 ° C hummingbirds appeared to prioritize insulation over aerodynamics as their plumage remained "fluffed" during hovering. Hummingbirds appeared to manage heat budgets by varying their physiological and behavioral strategies across all trials. Our data show that hummingbirds which are adapted to use hover flight for foraging and pollination also have physiological and behavioral tools to fulfill their ecological role in a variety of conditions.

50-4 Powers, AK*; Tabin, C; Harvard Medical School, Blavatnik Institute of Genetics, Boston, MA; *amanda_powers@hms.harvard.edu*
The genetic basis of orofacial features in the blind Mexican cavefish
Evolutionary model systems have emerged as a rich source of natural genotypic and phenotypic variation, from which we can characterize the genetic architecture underlying morphological features. The Mexican tetra (*Astyanax mexicanus*), inclusive of interfertile river (surface)- and cave-dwelling morphs, provides a powerful comparative paradigm to study the genetic basis of a variety of traits evolving under extreme environmental pressures. Cavefish harbor numerous craniofacial differences compared to their surface-dwelling counterparts, including an elongated lower jaw (underbite) and an increase in the number of teeth. In order to investigate genes underlying orofacial traits, we performed Quantitative Trait Loci (QTL) analysis across individuals from an F_2 hybrid pedigree. We discovered significant QTL for bite, tooth size, and tooth number. An underbite, decrease in upper jaw tooth size and increase in tooth number are all associated with the homozygous cavefish genotype. We further explored candidate genes associated with significant QTL regions using BLAST and GO terms analyses. To understand why these changes evolved in cavefish, we performed

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feeding behavior assays in hybrids with both underbite and overbite phenotypes. Taken together, this work provides novel insight into the genetic regulators of facial bone and tooth development in the context of trait evolution.

9-5 Powers, MJ*; Martz, LD; Weaver, RJ; Burton, RS; Hill, GE; Auburn University, University of California, San Diego, University of Texas at Austin; *mjp0044@auburn.edu*

The link between mitochondrial metabolism and pigment production in interpopulation crosses of copepods

Interpopulation crosses between divergent populations of *Tigriopus californicus* copepods have revealed breakdown in metabolic and life history traits. This breakdown has been attributed to incompatibilities in the electron transport system and in DNA replication or transcription in the mitochondria. These incompatibilities can manifest as fitness loss in offspring, where some hybrids may display variable life history traits and energy production. *T. californicus* produce a red carotenoid pigment called astaxanthin from precursors obtained exclusively through their diet. Across taxa, the biosynthesis of red carotenoids is hypothesized to be linked to individual quality, possibly through shared metabolic pathways with oxidative phosphorylation. However, whether some *T. californicus* hybrids suffer a loss in the ability to produce red carotenoids has not been tested. Here, we tested whether astaxanthin production varied in hybrid copepods and among established recombinant inbred lines (RIL's) from interpopulation crosses. Further, we tested whether astaxanthin production was related to mitochondrial metabolism and offspring development. We found that copepods from some hybrid lines produced less astaxanthin than copepods from corresponding parental lines, while other hybrid lines did not. Astaxanthin production was not significantly associated with offspring development in RIL's. Interestingly, we found that astaxanthin was negatively related to ATP production, but was significantly positively related to an enzymatic marker of mitochondrial density and oxygen consumption. These results indicate that astaxanthin production may be influenced by mitochondrial density and the rate of oxidation reactions.

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12-8 Price, CT*; Ford, MP; Santhanakrishnan, A; Oklahoma State University; *askrish@okstate.edu*

Roles of body and tail angles on metachronal swimming performance

Freely-swimming crustaceans such as krill can swim individually and also in large schools, being able to rapidly maneuver in all directions using a swimming technique called metachronal paddling. Metachronal paddling involves the out-of-phase stroking of closely spaced limbs starting from the back to the front of the animal. A number of factors, including phase lag and stroke amplitude can affect metachronal swimming performance, and various species have been observed to flex their abdomen and tail in order to vector the thrust to rapidly maneuver. Also, the body angle has been observed to be altered in Antarctic krill for varying gaits. However, no studies to date have quantified how changing body angle and tail angle impacts swimming performance and underlying flow field characteristics. Using high-speed videography and time-resolved planar particle image velocimetry measurements on a dynamically scaled paddling robot, we examined how variation of the body and tail angles impact swimming performance, wake momentum, and angle of the wake. Increasing the angle between the tail and the longitudinal axis of the body resulted in orienting the wake more vertically, as well as slightly decreasing the total momentum of the wake. Changing the body angle resulted in larger changes in wake angle and swimming speed. The implications of the observed flow fields on behavorial needs such as feeding and schooling will be discussed.

BSP-8-5 Prichard, MR*; Merritt, JR; Root, J; Grogan, KE; Maney, DL; Emory University; *mpricha@emory.edu*

Epigenetic regulation of the VIP gene in a polymorphic songbird

Pathways between genotype and phenotype, especially a behavioral phenotype, are complicated by many levels of biological organization, making direct connections difficult. An ideal model in behavioral genetics is the white-throated sparrow because a rearrangement of the second chromosome, which constitutes a supergene, is linked with territorial aggression. Birds with a copy of the supergene are more aggressive than those without it. The

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supergene has captured *VIP*, which encodes vasoactive intestinal peptide, a neuromodulator already known to be causal for aggression in other songbirds. *VIP* expression is higher in the anterior hypothalamus of birds with the supergene than in those without it and expression of *VIP* in this region predicts the level of territorial aggression regardless of genotype. Thus, *VIP* is a strong candidate to mediate this behavioral polymorphism. Here, we aimed to identify epigenetic mechanisms that could contribute to differential expression of *VIP*. We extracted and bisulfite-converted DNA from samples of hypothalamus in wild-caught adults and nestlings, and used high-throughput sequencing to measure DNA methylation of a region 1.2kb upstream of the *VIP* start site. We found that this region was less methylated in birds with the supergene than in those without it. In addition, methylation differed between the supergene allele and the standard allele at specific sites within this putative *cis*-regulatory element. This differential methylation provides a potential explanation for differential *VIP* expression in this species. This work represents an initial step toward understanding how differentiation of genetic sequence inside supergenes leads to the development of alternative behavioral phenotypes.

38-9 Probst, CM*; Ralston, J; Bentley, I; University of Notre Dame, Indiana, Saint Mary's College, Notre Dame, Indiana; *cprobst@nd.edu*
The effect of climate on bill morphology divergence in Toxostoma thrashers
Bird bills possess an important thermoregulatory function as they shed heat via environmental heat exchange. Previous studies have demonstrated that birds in warmer climates tend to have larger bills than those living in colder climates, as larger bills can radiate more heat. Because heat is released without water loss, this cooling method is especially advantageous in water-restricted habitats. Here, we examine the influence of climate on bill morphology in *Toxostoma* thrashers, a group of 10 North American species that vary in bill morphology and occupied climate niche, with several species inhabiting arid or semiarid climates. Past examinations of thrasher bill morphology have only considered foraging, leaving unanswered the role of climate in divergence within this group. We photographed 520 *Toxostoma* museum specimens

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encompassing all 10 species, and calculated bill measurements from the photos using a MATLAB computer program created specifically for this purpose. For each species, we calculated occupied climate niche using data from WorldClim describing temperature and precipitation means and extremes. We then used multiple linear regression to determine how climate influences bill morphology. Preliminary analyses do not suggest a significant relationship between bill morphology and climate variables. This potentially indicates that other factors, such as foraging behavior, have played a stronger role in shaping the bill morphology of this genus.

30-2 Proffitt , MR*; Smith, GT; Dept. Biol., Indiana University, Bloomington IN; *mrproffi@iu.edu*

Variation in androgen receptor sequence corresponds to variation in androgen responsiveness across two ghost knifefish species

Evolutionary changes in steroid hormone receptor sequences have led to species variation in the ligands of these receptors and hormone function (Eick et al., 2012). This study examined how variation in responsiveness of a sexually dimorphic communication signal (the electric organ discharge of electric fish) to androgens might be related to evolutionary changes in the sequence of the androgen receptor (AR). Knifefish communicate with continuously produced electric organ discharges (EODs). In many species, EOD frequency (EODf) differ between males and females. Sex differences in EODf are regulated by effects of steroid hormones in the hindbrain pacemaker nucleus (Pn). Two species of knifefish (*A. albifrons* and *A. leptorhynchus*) differ substantially in the efficacy of different androgens on EODf. 11-ketotestosterone (11-KT) robustly masculinizes EODf in both species (Schaefer and Zakon, 1996). However, 5-α dihydrotestosterone (5-α DHT) masculinizes EODf in *A. albifrons*, but does not affect EODf in *A. leptorhynchus* (Meyer et al., 1987). Two different AR genes (ARα and ARβ) were expressed. ARα had the highest expression in the Pn of both species. ARα was less conserved between *A. albifrons* and *A. leptorhynchus* than ARβ of these two species. When knifefish ARs were compared across species, ARα of *A. leptorhynchus* had more changes than other knifefish in key regions of the ligand binding domain. These "key regions" are residues in

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humans that directly interact with 5-αDHT (Ogino et al., 2015). These specific residues also tend to be highly conserved in AR of teleost fish. Overall, our data suggests that evolution of AR gene sequence change androgen selectivity in ways that could impact hormonal regulation of behavior.

15-3 Protopopova, A; The University of British Columbia; *a.protopopova@ubc.ca*

The role of companion animal scientists in anticipating and adapting to the fallout of climate change

The current pandemic, on-going societal tensions, and recent natural disasters are a stark reminder that we are living in a climate crisis. Climate scientists and policy makers have asked each discipline to anticipate and create adaptation plans in preparation for a worsening future. In this theoretical talk, I highlight related companion animal issues and discuss what role scientists may play in adapting to the fallout of climate change. I will draw on examples from my Human-Animal Interaction lab, where we have re-focused our research on questions of climate adaptation, such as discriminatory practices in animal sheltering, housing insecurity and pet ownership, reducing pet food waste, and the effects of socioeconomic factors on pet disaster planning. The talk is a "call-to-arms" for companion animal scientists to join forces and develop an effective climate adaptation plan for our field.

BSP-6-3 Pruett, JE*; Warner, DA; Auburn University; *jep0057@auburn.edu*

Developmental temperatures differentially affect survival across life stages

The environment dramatically influences phenotypic variation either by acting as a selective force on existing phenotypes, or via phenotypic plasticity. Plastic responses to the environment can be observed across traits, taxa, and life stages, but developmental stages are particularly sensitive to environmental influence. Furthermore, plastic responses during these stages can interact and carry fitness consequences into later life stages. Developmental plasticity can lead to significant variation in phenotypes, the causes and consequences of which are poorly understood, especially

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across entire lifespans. The brown anole (*Anolis sagrei*) has well-documented plastic responses to components of the developmental environment, such as temperature, which can affect incubation duration, survival, and other fitness-related traits. However, many studies use few treatment groups and lack the capacity to provide well defined reaction norms. To determine the effects of incubation temperature across life stages, we incubated brown anole eggs under eight constant temperatures and conducted a field-based mark-recapture study on the resulting hatchlings. We generated high-resolution reaction norms for several phenotypic traits, and found that there was variation in thermal response curves with respect to egg hatching success and phenology of hatching. Although high temperatures were thermally stressful to embryos, they also reduced incubation duration and led to earlier hatching. In turn, earlier hatching increased the probability of survival to adulthood. Consequently, the optimal incubation temperature differs among life stages. This study emphasizes the complexity of plastic responses during development and their potential effects on fitness across the lifespan.

74-3 Pulliam, JN*; Salcedo, MK; Weiss, TM; Hernandez, AM; Socha, JJ; Virginia Tech, Harvard University; *jppulliam3@vt.edu*
Climbing strategies of cicadas across vertical 'gaps' of low friction
Diverse limb adaptations allow insects to navigate complex terrain while maintaining stability, enabling behaviors such as climbing waxy leaves, digging deep in soil, and skimming the surface of water. Tarsal structures (akin to 'feet') such as claws or setae ('hairs') allow insects to attach and adhere to uneven plant and water surfaces. Periodical cicadas (genus: *Magicicada*) emerge en masse, and as females lay eggs in trees, they show distinct preferences for small diameter branches or trunks. Often, these oviposition locations are at the ends of tree branches, where stability is key and wind could cause slippage. How cicadas navigate, grip, and support themselves on thin tree surfaces is largely unknown. Here, we investigated how *M. septendecim* and *M. cassini* (Brood IX) climb and interact with areas of low friction using PVC and plastic pipes as models for vertical perches. We recorded 701 trials of cicadas climbing on pipes of four diameters

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(5.0, 15.9, 21.6, 33.5 mm) using a synchronized camera array (Hero 4 Black, GoPro). The pipes were wrapped in green terrarium matting to provide a high-friction surface for climbing. A single gap in the matting (gaps ranged 6 to 36 mm) revealed the smooth pipe surface as a low-friction slip challenge, with gap size presented randomly. For the three largest diameter pipes, success rate of crossing decreased with increasing gap size, from 85.4% (6 mm) to 10.5% (30 mm); cicadas could not cross a gap of 36 mm. However, on the smallest diameter pipe, cicadas crossed every gap size, with an overall 100% success rate. To explore the kinematics of failure in more detail, we conducted additional trials using three synchronized high-speed Photron cameras recording at 2000 fps. Lastly, SEM images were used to compare male/female tarsal morphology. These data contribute to our understanding of how insects locate oviposition sites, maintain stability, and navigate tree branches during climbing.

82-8 Putney, J*; Sponberg, S; Georgia Tech, Atlanta, GA; *jputney3@gatech.edu*

Spike timing changes between power muscles in pitch and roll turns of a hawk moth, M. sexta

In the Lepidopteran flight system, two muscle pairs - the dorsolongitudinal (DLM) and dorsoventral (DVM) muscles - power the downstroke and upstroke of the wing, respectively. They are activated synchronously by neural spikes unlike in *Drosophila*, where high wing beat frequencies demand asynchronous stretch activation. Neural control of turns may differ in synchronous fliers since precise timing control of power muscles is possible. In the hawk moth, the bilateral timing between left and right DLMs and DVMs are correlated with yaw turns, and DLM timing differences causally control power output during yaw turns, likely by inducing side asymmetries. However, few experiments have investigated how the timing of power muscles change in pitch and roll turning in synchronous flight, or if timing between DVM and DLM activations is important for facilitating these turns. We drove hard turns around the flight axes - pitch, roll, and yaw - during tethered flight in hawk moths (*M. sexta*) while simultaneously recording the DLM and DVM activations and turning torques produced. We found differences in motor output between pitch, roll, and yaw turns. We show that in

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roll turns, the ipsilateral DLM leads the contralateral DLM timing, potentially introducing wing stroke asymmetries. We also demonstrate an increased length of time between DVM and DLM activation when a moth is pitching up, suggesting a change in the downstroke duty factor and a potential shift in mean flapping angle. Timing differences in power muscles may contribute to an alternate control strategy for pitching and turning compared to *Drosophila*, where steering muscles like the first basalar protract the wing and adjust wingstroke amplitude. These patterns give insight into how synchronous flight power muscles control turning with precise timing coordination.

100-4 Quertermous, HM*; Earley, RL; University of Alabama; *hmquertermous@crimson.ua.edu*

Initiation of sex change to male in socially subordinate mangrove rivulus hermaphrodites

While sexual phenotypes are typically thought of as permanent, many marine fishes change sex during adulthood, a strategy called sequential hermaphroditism. Multiple factors, including changes in gene expression patterns and associated endocrine/molecular processes, contribute to altering behavior and morphology required for sex change. Social status is often a key driver behind the "decision" to change sex. We investigated whether social interactions trigger sex change from hermaphrodite to male in mangrove rivulus fish. Hermaphrodites reproduce mainly via self-fertilization, meaning that switching to male could be costly for future reproduction because only hermaphrodites have reproductive assurance. However, changing sex to male could be a survival tactic in difficult conditions, especially given the high cost of maintaining ovaries. In this study, we placed pairs of hermaphrodites together for eight weeks, allowing dominant-subordinate relationships to form and took videos to quantify aggressive and submissive behaviors. We examined external appearance and gonadal histology to quantify features indicative of sex change. Using qPCR, we examined patterns of expression for genes responsible for the development of female-typical or male-typical traits in the brain, liver, and gonad. We predicted that subordinate fish would show an increased propensity to change sex due to the energetic costs of engaging in antagonistic interactions

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with dominant individuals. We expect to see greater development of testicular tissue and regression of ovarian tissue in subordinates, along with upregulation of male-biased and downregulation of female-biased genes. This study will increase our knowledge of how social interactions affect physiological processes that dictate sexual phenotype.

103-5 Quigley, ZM*; Blob, RW; Kawano, SM; George Washington Univ., Clemson Univ.; *zmgquigley@gwu.edu*

Kinematic comparisons between mudskipper fins and salamander limbs during terrestrial locomotion

Amphibious salamanders and fishes are often used as functional analogues for tetrapodomorphs to model the evolution of terrestriality. Although terrestrial salamanders have been the primary taxon used to model the locomotion of stem tetrapods, recent paleontological analyses show that the terrestrial locomotion of any early tetrapod, *Ichthyostega*, was more comparable to ‘crutching’ in mudskipper fish. Kinetic data published on tiger salamanders (*Ambystoma tigrinum*) and African mudskippers (*Periophthalmus barbarus*) indicated that the ground reaction forces were inclined more medially in mudskipper pectoral fins, which might elevate bending stresses in the fin bones. However, kinematic data are needed to test whether loading regimes differ between fins and limbs. To compare the function of fins and limbs during terrestrial locomotion, we quantified the 3D kinematics of mudskipper pectoral fins and then compared these to published data on *A. tigrinum* forelimbs. Preliminary results show kinematic differences between these pectoral appendages. For example, the pectoral fin is more extended than the forelimb during stance. In the fin joint that is functionally analogous to the wrist in salamanders, maximum flexion reaches a similar magnitude but occurs earlier in mudskippers. These kinematic differences and the ‘hyper sprawling’ fin posture of mudskippers help explain what may be driving kinetic differences published between two functional analogues for early tetrapods. These data provide a foundation for estimating bone stresses in mudskipper fins during terrestrial locomotion compared to salamander limbs, providing insights into whether locomotor performance is driven by functional innovation

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due to structural changes (fins vs. limbs) or mechanical similarity due to many-to-one mapping.

82-5 Quinlan, PD*; Cho, AK; Katz, PS; University of Massachusetts, Amherst, MA; *pquinlan@umass.edu*

Characterization of visually-guided behaviors by the nudibranch, Berghia stephanieae

Although it was previously thought that nudibranchs use their eyes for just detecting light, we found that they exhibit visually-guided behaviors that are distinct from light-dark preference. To examine how nudibranch behavior is guided by light, we tracked the paths of locomotion of the nudibranch *Berghia stephanieae* in response to different visual stimuli using DeepLabCut. In a light-dark preference test, *Berghia* spent a majority of time in the dark. This occurred for both hungry and sated animals. *Berghia* crawled more slowly in the dark portion of the arena. When presented with a black stripe on a white background outside of the arena, *Berghia* reliably navigated to the stripe. This behavior was hunger state- and context-dependent; animals did not approach a stripe when hungry or in the presence of a food odor. *Berghia* also approached a stripe that was isoluminant with the background. These results suggest that visual information guides *Berghia*'s behavior with two distinct mechanisms. While the level of ambient light modulates speed to cause *Berghia* to spend more time in the dark, *Berghia* may be making spatial comparisons of light to navigate to a stripe.

56-9 Rader, JA*; Waldrop, LD; Hedrick, TL; UNC Chapel Hill, Chapman University; *jrader@live.unc.edu*

Does load bearing constrain avian wing morphology?

Many selective pressures influence the shape of bird wings and their adaptation to the myriad of flight behaviors known from extant species. While some of these pressures may be synergistic, functional demands may also result in opposing pressures, and morphological diversification may be constrained. For example, wings must have an aerodynamically appropriate shape for flight, but also be strong enough to resist the aerodynamic and inertial loads they experience. The balance of these pressures differs among

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species with different flight styles and ecologies, and wing morphology is expected to vary accordingly. Two-dimensional (2D) shape traits, such as aspect ratio, and three-dimensional (3D) attributes of wing morphology including camber and thickness contribute to aerodynamic function and vary significantly among species. In prior work, we found that a combination of high aspect ratio and high camber produced high coefficients of lift (C_L), while high aspect ratio and moderately low camber produced higher lift-to-drag ratios (C_L/C_D). A morphological survey of bird wings found that long-distance gliding birds trended toward high camber, contrary to predictions that their wings would be adapted to produce high C_L/C_D. We hypothesize that the structure of bird wings may exclude them from the seemingly more efficient configuration of high aspect ratio and low camber. We propose that because camber in birds is intrinsically linked to the cross-sectional thickness of the wing, that the thickness required to resist bending forces also imposes a minimum bound on wing camber, potentially constraining morphological evolution. We explore the relationship between wing thickness and camber among birds, and use a beam-theory model of structural stiffness to describe how structural demands constrain the evolution of wing morphology.

71-8 Rainbow, MJ*; Mack, ZM; Lee, ECS; Orr, CM; Queen's University, University of Colorado; *michael.rainbow@queensu.ca*

Determinants of maximum wrist extension in humans and chimpanzees

Compared to humans, the chimpanzee has limited wrist extension, presumably to facilitate knuckle walking. The greater range of extension in the human wrist is thought to be an adaptation for dextrous and powerful manipulation of tools and throwing. The purpose of this study was to determine whether features of the scaphoid - considered a bridge between the carpal rows - influence maximum extension in both humans and chimpanzees. Using surface models acquired from CT, we performed separate shape analyses on humans (n = 9) and chimps (n=5), and regressed max extension as a function of shape. We also examined max extension as a function of the neutral wrist position of the trapezoid-scaphoid contact centre, scaled to centroid size. Scaphoid shape predicted max extension strongly in humans (PC2) and weakly in chimps (PC1), but the modes captured different features in both groups, suggesting no

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specific feature of the scaphoid influences extension mobility across species. We also found the trapezoid contact location was strongly related to max extension. In humans, extension increased in subjects with a distally located trapezoid. Chimpanzee trapezoids were much more proximal compared to humans, which may help explain their comparatively limited extension mobility; however, we did not detect a relationship between trapezoid location and max extension within chimps. These results highlight that while scaphoid morphology influences within species ROM, an approach that integrates the neighboring bones may be required to infer important differences in function across species. Mapping wrist form to function may provide insight into how selective pressures altered the musculoskeletal system as these groups diverged from our last common ancestor.

76-2 Rajput, AP*; Meegaskumbura, M; Eco.Evo.Devo Lab-Group, Guangxi Key Laboratory of Forest Ecology and Conservation, College of Forestry, Guangxi University, Nanning Guangxi, China ; *amrapali20@outlook.com*

Caecilian harbor a distinctive microbiome: Ichthyophis bannanicus (Amphibia, Gymnophiona) and anuran larvae compared

Animal-associated microbiomes play an important role in metabolic activities including immune functions of hosts. Microbiome related work, facilitated by next-gen approaches are now emerging for amphibians, but the microbiome of caecilians that constitute of 3% of the amphibians are unknown. Here we explore the gut and skin microbial diversity of larval caecilians. We used 16S rRNA gene amplicon sequencing to evaluate the bacterial communities present in the gut and skin samples of larval *Ichthyophis bannanicus* (n = 13), a common caecilian distributed across South-East Asia. Our studies showed that gut and skin bacterial communities included Bacteriodetes, Proteobacteria, Firmicutes, Verrucomicrobia, and Actinobacteria at the phylum-level core microbiome, though the percentage of the bacterial phyla were significantly different between gut and skin samples. The similarity between the gut and skin may be attributed to the life history stage. The microbiome at phylum level in anurans (frogs and toads) is known to consist of mainly Proteobacteria, Fusobacteria, Firmicutes, Bacteriodetes and Cyanobacteria. Proteobacteria are thought to play key role in

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preparing the gut for colonization by anaerobes required for healthy gut function by consuming oxygen, and lowering redox potential in the gut environment. Bacteriodetes perform metabolic conversions that are needed for the host such as degradation of proteins or complex sugar polymers. Data for caudate (salamanders and newts) larvae is absent. However, it appears that larvae of different orders of amphibians have distinct bacterial phyla.

96-11 Ramaswamy, SS*; Sane, SP; National Centre for Biological Sciences, Bengaluru and SASTRA University, Thanjavur, National Centre for Biological Sciences, Bengaluru; *sreesubhar@ncbs.res.in*

The role of pheromones in mound-building behavior in termites

Mound-building termites build exquisite, massive structures out of soil. These mounds are overground and have numerous corridors and galleries leading to the subterranean nesting chambers. They also farm fungal gardens where specific fungi are cultured. This architecture is thought to enable gas exchange and thermoregulation in addition to protecting the colony against predators and abiotic factors. It is not understood how termites coordinate to build intricate structures given that they do not possess image forming eyes. We have previously showed that termites rapidly mend any breach in their mound, being recruited there due to sensory cues, which are light-based but may also contain a chemical component. We devised an experimental assay to measure how termites determine the site of building. Specifically, we tested the Stigmergic hypothesis, which suggests that termites recruit other termites using chemical cues that are embedded in the soil. We show that termites are attracted to soil that has been previously worked on by other termites, over control soil from the environment. Removal of volatile cues by baking the freshly built soil reduces its preference to termites, suggesting that termites add a chemical cue to the soil while processing it. Indeed, adding the chemical extract from freshly built soil renders control soil attractive. We thus find that termites chemically manipulate the soil which attracts them to the building site. Experiments with soils from native versus foreign mounds suggest that non-volatile cues are important for discriminating self from a non-self mound. Thus, we propose that a hierarchy of chemicals embedded in the soil act as a

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chemical address for their mounds, and that these signals are stable even at high temperatures.

BSP-5-1 Ramesh, A*; Jones, T; Dorleans, R; Totaro, L; Bashey, F; Indiana University, Bloomington; *aramesh@indiana.edu*

Can parasite aggregation stabilize host-parasite populations? Linking individual parasite behaviour to population dynamics

Critical to predicting the impact of disease spread is understanding how behaviour of individual parasites influences dynamics at the population scale. In parasites with a free-living stage, the decision to enter a host depends on information obtained from the environment. Assessing host availability and conspecific density is vital to maximizing individual fitness within a host, and subsequently affects population dynamics. We used two species of free-living entomopathogenic nematodes (EPNs) and a caterpillar host. Using soil mesocosms, we tested three competing hypothesis of parasite distribution among hosts: random, even, and aggregated distribution across varying levels of host and parasite densities. Parasite distribution among hosts are critical in determining individual fitness and thus stability of host-parasite dynamics. Overall, we found evidence to support the aggregated distribution hypotheses in both species of EPNs. Aggregation increased with parasite density, but host density had no effect. Aggregation had non-linear consequences on fitness. When too many parasites colonized an individual host, intraspecific competition led to reduced female size. Alternatively, when too few parasites colonized a host, its resources were not effectively exploited, and individual females again showed reduced size. As female size affects fecundity, aggregation behaviour can strongly reduce per capita fecundity, facilitating stabilization of host-parasite dynamics. We are currently examining the magnitude of this effect using mathematical modelling parameterized from this study. Our study thus supports prior work on EPNs which also showed aggregated behavior and extends our understanding by linking this behavior to individual fitness and its impact on population dynamics.

24-10 Ramesh, D*; Fu, Q; Wang, K; Othayoth, R; Li, C; Johns Hopkins University; *dramesh6@jhu.edu*

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A sensorized robophysical model to study snake locomotion in complex 3-D terrain

The ability to sense contact forces helps animals understand a novel environment and adjust to move through. Generalist snakes are presumably exceptionally good at doing so, as they quickly and stably traverse various complex terrain by transitioning across strategies. However, we know little about how distributed force sensing is used to control and adjust the deformation of their elongate body in response to the terrain to generate effective locomotion. Discovering the physical principles of this process will help uncover the feedback control strategies of generalist snakes in complex terrain. It will also help snake robots better traverse challenging terrain like earthquake rubble. Here, we developed a sensorized snake robot and used it as a physical model to discover the physical principles of distributed force sensing and feedback control of snake locomotion in complex 3-D terrain. Because commercial force sensors are bulky and expensive, we applied a low-cost, flexible pressure sensor array distributed around all body segments. Calibration showed that the sensor array can measure distributed ground reaction forces of 10% body weight at 30 locations along the body at 10 Hz, despite disturbance from self-deformation of the moving body. We are developing force-based feedback control to further enable variation of control strategy. Based on our animal observation (see other talk by Fu, Astley, Li, Snakes traversing complex 3-D terrain), we will test the robot in complex terrain to understand how forces are related to the observed motion. We are also exploring ways to increase the sensor array's sensitivity and developing a sensorized complex terrain platform to measure distributed ground reaction forces in biological snakes.

63-4 Ranchod, PN*; Weier, D; Steffenson, M; St. Edward's University; *pranchod@stedwards.edu*

The effect of colony relocation on Italian honeybee immunological response

Colony collapse disorder (CCD), the leading cause of sudden death in *Apis mellifera* (Italian honey bees), is characterized by worker bees fortuitously leaving their colony in pursuit of nutrients and resources; however, these bees fail to return to the hives,

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ultimately leaving behind a queen, brood, and a small number of worker bees. While the primary cause of this phenomenon has not yet been discovered, agricultural pesticides, invasive *Varroa* mites, pathogens, and stress-related to habitat change are among the leading factors hypothesized to contribute to this phenomenon. The goal of this study was to observe how environmental and habitat changes due to colony migratory management, a common practice in which bee colonies are transported across the country in order to pollinate large- scale agricultural products, can affect the immunology of Italian honey bees over time since the period of colony establishment. Established colonies from the Dallas-Fort Worth area were transported and brought to St. Edward's University. Started upon arrival of the bees, bees were collected and hemolymph was extracted biweekly to identify the impact on the bee's immunological response. Common beekeeping techniques were also performed to simulate normal beekeeping operations as closely as possible. Samples were then subjected to several colorimetric assays to determine protein concentrations related to immune functioning. Preliminary data indicates that bees seemed to have an increase in overall protein concentrations, as well as prophenoloxidase (a protein commonly utilized by invertebrates in immune functioning) post-transport. Bee basal immune activity also seems to increase in response to environmental factors that may cause stress, such as thunderstorms. Samples are currently being subjected to assays to quantify the antioxidant peroxidase, with results forthcoming.

81-9 Rathore, S*; Meece, M; Cook, T; Buschbeck, E; University of Cincinnati, Biological Sciences, Cincinnati, OH, Wayne State University, Detroit, MI, USA; *rathorst@mail.uc.edu*

Investigating the role of the transcription factor Cut in the lens secreting Semper cells of insect compound eyes

The cell types in a typical insect visual system are broadly divided into photoreceptor neurons and support cells. While photoreceptors have been studied extensively, support cell biology remains relatively understudied. Here we focus on a subset of support cells in the adult *Drosophila* compound eye called Semper cells which cage the photoreceptors. These cells provide multifunctional glial support to photoreceptors and also secrete

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the lens; hence Semper cells are key constituents of a properly functioning fly eye. One of the best-known markers for *Drosophila* Semper cells is the homeodomain transcription factor Cut, yet the function of *cut* in Semper cells has not yet been elucidated. Based on its restricted expression to Semper cells, and its other known functions in sensory cell fate decisions and development, we hypothesize that *cut* is important for visual system development and/or function. To investigate this, we knocked down *cut*'s expression in the Semper cells using RNAi. This resulted in flies with rough eyes, suggesting a vital role for *cut* in eye development. We further characterized *cut* knock-down eyes for three aspects of ocular development previously shown to be influenced by Semper cells: lens focusing, photoreceptor neural activity, and photoreceptor morphogenesis. In each case, we find major deficiencies in animals lacking *cut* expression in Semper cells, suggesting a broad role for *cut* in Semper cell biology. Parallel studies on beetles will establish if *cut*'s expression and function could be conserved in the lens-secreting cells of other arthropods. Taken together, this study will provide further insights into eye-specific "ancient gene networks" which have been conserved across distant phyla.

103-4 Rawson, JRG*; Esteve-Altava, B; Porro, LB; Dutel, H; Rayfield, EJ; University of Bristol, Pompeu Fabra University, University College London; *jr17384@bristol.ac.uk*

Building a tetrapod: skull topology across the water-to-land transition

The vertebrate skull has undergone periods of bone loss or fusion throughout its evolution, particularly at the origin of major clades. This trend, known as "Williston's Law", has been suggested to result in more mechanically efficient skulls. The origin of tetrapods occurred alongside major changes in cranial structure, which have been linked to consolidation of the skull as feeding mode changed across the water-to-land transition. It has therefore been inferred, but not tested, that Williston's Law explains changes in skull anatomy across this major event in vertebrate evolution. We quantified skull architecture across the water-to-land transition, using a network-based approach to analyse topological features of 17 'fish' and 93 tetrapod skulls.

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Moreover, this large sample allowed us to quantify the evolution of the structural disparity of the skull from the Early Devonian to the present day. We found that skull architecture changes significantly across the water-to-land transition, showing increased topological complexity and decreased modularity. This suggests that bone loss and fusion lead to greater connectivity among the remaining elements, disputing the assumption that Williston's Law leads to anatomical simplification. We found that skull topological disparity decreases at the origin of Tetrapoda, followed by a second significant drop at the end of the Devonian congruent with the Hangenberg extinction event and continuing into Romer's gap. We therefore conclude that the architecture of tetrapod skulls has been shaped by both mechanical constraints associated with bone loss as well as influence from external extinction and diversification events.

66-6 Reade, JE*; Schwab, RK; Jankauski, MA; Montana State University; *josephreade.school@gmail.com*

Influence of flexural rigidity on force production in flapping wings

In flexible wings, deformation and aerodynamic forces are strongly coupled. However, the high-fidelity computational fluid dynamics and finite element analysis used to estimate structural-aero mechanics are computationally expensive and impractical for parameter studies that consider variable wing geometry. Here, we develop a reduced-order fluid-structure interaction model to determine the forces experienced by a two-dimensional wing undergoing pitch-plunge motion, and use the model to study the effects of variable flexural rigidity on force production. Wing deformation is calculated using the assumed mode method. The fluid model is a modified version of the unsteady vortex lattice method, a technique built on potential flow that treats the wing as a thin airfoil. By varying the thickness distribution of the wing, we can influence the rigidity and aerodynamics of the problem. Using kinematics and material parameters similar to those of a *Manduca sexta* wing, our model predicts that the maximum lift is generated when the wing is driven at roughly one-third of the its fundamental frequency, which is determined by the thickness distribution. Increasing the average thickness, and therefore the mass and

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stiffness, resulted in greater lift, though this may come at the cost of increased power consumption. Additionally, the driving-to-natural frequency ratio associated with maximum lift increased slightly with wing thickness. The lift generated by homogeneous wings is strongly affected by wing mass, while the lift of exponentially tapered wings is relatively unchanged. The work described in this paper will lead to more powerful models that can be used with varied geometries and three-dimensional kinematics.

91-6 Redak, CA*; Stevison, LS; Halanych, KM; Auburn University ; *czr0057@auburn.edu*

Population genomics of Saccoglossus kowalevskii

The hemichordate *Saccoglossus kowalevskii* has been used as a developmental model to offer insights into the evolution of developmental mechanisms in deuterostomes, especially chordates. Along with echinoderms, they make up Ambulacraria, the sister clade to chordates. To date, most studies on *S. kowalevskii* have used a single population located near Woods Hole, Massachusetts. However, the species is known to occur from Maine to South Carolina. Very little is known about the genetic diversity of the Woods Hole population, and even less about diversity among other populations. Thus, to explore the diversity within and between the Woods Hole and other populations, we conducted population genomic analyses using data from whole genome sequencing. To do this, we collected 20 acorn worms at 4 sites (South Carolina, Virginia, Delaware, and Massachusetts), and sequenced whole genome DNA to ~20X coverage using paired-end Illumina Hi-Seq. There was little variation in our mapping success for whole genomes from all populations to the reference genome from Woods Hole. We characterized both the within and between population heterozygosity and tested for signals of geographic relatedness by analyzing FST, nucleotide diversity, and observed heterozygosity. We also investigated signals of isolation-by-distance and linkage disequilibrium. Because of the dependence of developmental projects on the Woods Hole population, we hope this study serves as a resource for the Saccoglossus community to determine if other populations are sufficiently genetically similar, and suitable, for EvoDevo and ecological research. We additionally hope this study helps clarify some questions about the

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natural history of *S. kowalevskii* by understanding their within species genetic diversity.

S7-2 Reed, RD*; Brack, BJ; Cornell University; *robertreed@cornell.edu*

Origin of color in butterflies

Butterfly wings are graced by hues drawn from a palette both broad and deep. Our understanding of the pigments that generate many of these colors is surprisingly cursory, however. We have been working to understand the origin and diversification of ommochrome pigments in Nymphalidae - the largest and most diverse butterfly family. Ommochromes have an ancient origin within arthropods as red-hued visual filtering pigments, yet they appear to have a single origin as wing pigments in nymphalids. After they appeared as wing pigments, ommochromes rapidly diversified into many different pigments of different hues. Using a combination of comparative transcriptomics, HPLC, MS-imaging, genetic mapping, and CRISPR/Cas9 genome editing, we have made significant progress in identifying ommochrome genes and pigments in nymphalids. Interestingly we found that many novel major facilitator superfamily (MFS) transporter genes are involved in generating ommochromes of different hues. These genes are unrelated to well-known ommochrome ABC transporters in Drosophila (i.e., white and scarlet), and appear to have originated during several major Lepidoptera- and butterfly-specific gene family expansions. We also found that a single transcription factor called optix appears to act a master regulator of all ommochrome pigmentation in nympahlids - a function with no known precedent in other arthropods. Ultimately, the ommochrome gene network in butterfly wings is quite different from what has been described in other arthropods, and therefore a simple co-option-from-eyes origin scenario is difficult to support. Further, the large number of novel ommochrome genes we found in butterflies suggests that the diversification of butterfly wing coloration was facilitated by the expansion of pigment-related gene families.

34-3 Rees, BB*; Reemeyer, JE; Irving, BA; University of New Orleans, McGill University, Louisiana State University; *brees@uno.edu*

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Individual variation in standard and maximum metabolic rate correlates with gill morphology and cardiac bioenergetics

Standard and maximum metabolic rates (SMR, MMR) vary among individuals within a species in a reproducible fashion. Many morphological and physiological traits likely contribute to this variation, including the capacity for gas exchange at the gills and the ability of the heart to distribute blood to the tissues. Here, we estimated SMR and MMR by intermittent-flow respirometry of the Gulf killifish, *Fundulus grandis*, and determined whether these rates are correlated with gill morphology and cardiac bioenergetics. Gill filament length and filament number were determined as proxies of gill surface area. Oxygen consumption by permeabilized heart ventricles was measured by high-resolution respirometry at saturating substrate concentrations during the following respiratory states; LEAK, OXPHOS (ADP-stimulated respiration), and ET (maximum noncoupled respiration). General linear modeling showed that SMR was best predicted by body mass, total filament length, and cardiac oxygen consumption during ET (r^2 = 0.69), while MMR was best predicted by body mass, total filament length, and cardiac oxygen consumption during OXPHOS (r^2 = 0.79). Absolute aerobic scope (AAS) is the difference between MMR and SMR and represents the capacity of a fish to perform energetically costly activities above maintenance. Variation in AAS was predicted by body mass, total filament length, and cardiac oxygen consumption during OXPHOS (r^2 = 0.71). Cardiac metabolism in the LEAK state was not correlated with SMR, MMR, or AAS. These results suggest that the capacity for branchial gas exchange and aerobic cardiac metabolism are linked to intraspecific variation in aerobic metabolism of fish.

S6-11 Reichert, MS*; Carlson, NV; Enriquez, MS; Raja, SV; Oklahoma State University, Max Planck Institute of Animal Behaviour, University of Minnesota, Duluth, National Centre for Biological Sciences (TIFR); *michael.reichert@okstate.edu*

Signals, space and time: Exploring the spatiotemporal dimension of animal communication networks

Communication is a social process, and occurs in a network of signalers and receivers. While social network analysis has received enormous recent attention from animal behaviorists, there have been

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relatively few attempts to apply these techniques to communication networks. Communication networks have the potential to offer novel insights into social network studies, and yet are especially challenging subjects, largely because of their unique spatiotemporal characteristics. Namely, signals propagate through the environment, thus dissociating from the body of the signaler to influence receiver behavior. The speed of signal propagation and the active space of the signal will affect the congruence of proximity-based networks and communication networks; in extreme cases the signal may persist and only first be detected long after the signaler has left the area. Other signals move more rapidly and over greater distances than the signaler could possibly move to reach receivers. We discuss the spatial and temporal consequences of signaling in networks, and highlight the distinction between the physical location of the signaler and the spread of influence of its signals, the effects of signal modality (and multimodality) on communication network properties, the potential for feedbacks between network layers, and techniques for analyzing spatial and temporal change in communication networks along with relating these to social networks based on proximity.

S9-10 Remage-Healey, LR; University of Massachusetts Amherst; *healey@cns.umass.edu*

Estrogens synthesized in auditory circuits are neuromodulators of cellular physiology and behavior

Steroid hormones like estrogens have been traditionally considered to be circulating factors secreted by peripheral glands to impact brain function and behavior over long-term timescales (days-weeks). We now understand that estrogens in particular can be synthesized by neurons at synaptic junctions to have acute (secs-mins) actions on neural circuit function and behavior. Our work in this domain focuses on an auditory pathway in the songbird forebrain that exemplifies this capacity for local 'neuroestrogen' synthesis and action. We have developed evidence that brain-derived estrogens can fluctuate dynamically and locally when adults and juveniles hear songs, and that steroids can have minute-by-minute actions on auditory neuronal coding and communication behaviors. More recently, we have characterized the actions of estrogens on membrane receptors that regulate intrinsic and network properties

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of auditory neurons, as well as the way that estrogen synthesis guides learning of new sounds in juveniles and adults. Evidence from in vivo electrophysiology, patch clamp electrophysiology, in vivo microdialysis, and behavioral experiments will be discussed. Together, several lines of research from my lab and others is showing that brain-derived estrogens can act as neuromodulators of neural circuit function and sensorimotor-dependent behaviors.

6-2 Renn, SCP*; Zornik, E; Reed College, Portland, OR; *renns@reed.edu*

How Integrative is your Animal Behavior?

Tinbergen proposed the classic "Four Questions" suggesting that to fully understand a behavior one must not only study its mechanisms, development, function and evolution, but his classic paper also argued for the integration across these questions. In other aspects of animal behavior, the idea of integration has been emphasized as the need to address a question by integrating across biological levels of organization spanning genetic, physiological, organismal, social, ecological and evolutionary contexts. Yet another axis of integration stems from the comparative approach, aiming to identify patterns that span species, genera, and family levels.

'Integration' does not simply mean working at multiple points along a single axis or even incorporating multiple axes into a single research project. Rather, the results should be mutually informative within and among these axes drawing new insights to each. This push for integration has led some to question whether this might not lead to a state of "jack of all trades yet a master of none." We review recent attempts for integration in the published literature and ask whether the appropriate vessel for integration is the individual researcher, the research group, a complex collaboration, or a broader research community. This project is the product of an undergraduate seminar course at Reed College.

78-7 Reynolds, HS*; Sunnarborg, J; University of Kansas; *marareyn96@gmail.com*

Landscape structure and movement in the desert grassland whiptail Aspidoscelis uniparens

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Tradeoffs between finding food and avoiding predators influence where and how animals move through their habitats. In sparsely vegetated arid regions, plant cover and distribution can influence where predators and prey reside. We examine movement of *Aspidoscelis uniparens*, an asexual, insectivorous lizard that is prey to predatory reptiles and birds in the desert grasslands of SE Arizona. The goal of our study was to elucidate the tradeoff between predator-avoidance and finding food by experimentally testing the effect of vegetation distribution on movement. We established 5 field enclosures with artificial plants placed in uniform, mildly clumped, or highly clumped patterns and then conducted focal observations on marked lizards. We measured time spent moving, time under vegetation, step length, turn angle, and plant revisitation frequency. Turn angle, step length, time spent in vegetation, and time spent moving did not vary with plant distribution, but frequency of plant revisitation, and the tendency for an animal to move to the nearest plant varied significantly with plant distribution. In particular, animals in mildly clumped plots had lower median residence times and were more likely to revisit plants than animals in other treatments. Lizards in uniform plots were more likely to visit the nearest plant than lizards in mildly or highly clumped treatments. Turn angles and step length following a turn were negatively correlated in mildly and highly clumped plots, indicating that *A. uniparens* might engage in area restricted searching when plants are clumped. Our species of whiptail engage in a structured foraging strategy that improves the efficiency with which they find prey while they minimize predation risks.

81-6 Rheinsmith, S*; Quinn, T; Yopak, K; School of Biology and Marine Biology and the Center for Marine Science, University of North Carolina Wilmington, Wilmington, NC, United States , School of Aquatic & Fishery Sciences, University of Washington, Seattle WA, United States ; *sarahrheinsmith@gmail.com*

Ontogenetic shifts in the nervous system of the sockeye salmon, Oncorhynchus nerka

Sockeye salmon, *Oncorhynchus nerka* are anadromous fishes, which hatch in freshwater streams, migrate to sea, and later return to their natal stream to spawn. Correspondingly, they undergo vast

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changes in behavior, morphology, and environment throughout ontogeny. However, the sensory systems that mediate these migratory patterns are not yet fully understood, and no study to date has explored changes to the nervous system across their full ontogeny at these key life history stages, which may provide additional insights into shifts in sensory specialization. This study investigated the changes in brain size and brain organization of *O. nerka*, across 5 different life stages (fry, smolt, maturing adult, migrating adult, and spawning adult). The relative size of 6 major brain regions (olfactory bulbs, telencephalon, diencephalon, optic tectum, cerebellum, and medulla) was assessed using the ellipsoid method. As documented in other species with indeterminate growth, brain size increases significantly with body mass throughout ontogeny in *O. nerka*, with a steeper period of allometric growth during fry and smolt life stages, before tapering off at sexual maturity. Trends show allometric scaling of major brain regions varies throughout life, which may reflect the varying sensory requirements at key life history stages. These findings aid in better understanding of the development of the brain throughout life, highlighting that critical ontogenetic shifts in behavior and habitats may coincide with shifts in central development.

52-11 Rhoda, DP*; Segall, M; Polly, PD; Raxworthy, C; University of Chicago, Committee on Evolutionary Biology, American Museum of Natural History, Department of Herpetology, Indiana University, Department of Earth and Atmospheric Sciences; *drhoda6@gmail.com*

Causes and consequences of morphological integration in the hyperkinetic snake skull

The highly kinetic skull is a key innovation that allowed snakes to capture, manipulate, and swallow prey exclusively using their heads using the coordinated movement of 8 bones. Despite these unique feeding behaviors, patterns of evolutionary integration and modularity within the feeding bones of snakes in a phylogenetic framework have yet to be addressed. Kinesis in the snake skull may create arbitrary differences in the relative positions of bones, hampering the analysis of modularity using geometric morphometrics methods. Here, we use a high-density geometric morphometric dataset of 60 specimens and develop a new superimposition protocol to address the origin and patterns of integration in the mobile

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feeding bones of aquatic-foraging snakes. We find that the feeding bones are highly integrated, driven predominantly by functional selective pressures. The most supported pattern of modularity contains four modules each associated with distinct functional roles: the mandible, the palatopterygoid arch, the maxilla, and the suspensorium. Further, the morphological disparity of each bone is not linked to its magnitude of integration, indicating that adequate biomechanical solutions to a wide range of feeding ecologies and behaviors is readily evolvable within the constraint due to integration in the snake feeding system.

S3-6 Rico-Guevara, A; Univ. of Washington; *colibri@uw.edu*
Hummingbird bill-flower matching
One of the reasons why flowering plants became the most diverse group of land plants is their ability to associate with animals to enhance their reproduction. Some of the earliest examples of this mutualism involved insects looking for food in plants and inadvertently pollinating them. Vertebrates are latecomers to these mutualisms, but birds present many nectar-feeding clades and repeated convergent evolution of bird-pollinated plants is also striking both in traits and diversity. One particular set of convergences both among these birds and plants has long attracted the attention of researchers: the match between the shape/size of bills and flowers. Traditional explanations for the coevolution of bill-flower matching include that bird-pollinated plants evolved traits, such as long and thin corollas, to prevent specific visitors (e.g. insects) from accessing the nectar, and that increased matching benefits both the bird (nectar extraction efficiency) and the plant (pollen transfer). Focusing on a highly-specialized group, hummingbirds, I present a workflow to examine the expected benefits from the bill-flower matching. This theoretical and methodological framework includes experiments under controlled conditions with captive birds (e.g. variable nectar access and properties), in semi-controlled conditions with free-living ones (e.g. PIT-tagged hummingbirds), and ways to quantify performance during actual floral visits (e.g. high-speed videography) in the wild. I propose to link inferences from experiments and natural behaviors to validate emerging models of nectar extraction and hummingbird energetics. Additionally, I

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discuss evolutionary forces, other than nectar-feeding, on the evolution of hummingbird bills and foraging behavior, that may influence their performance and behavioral strategies, ultimately shaping the interactions with competitors and the plants they pollinate/feed from.

S3-13 Rico-Guevara, A*; Green, PA; University of Washington, University of Exeter; *jjsocha@vt.edu*

Q&A on sexual selection: Brennan, Johnson, Clark, Laidre, and Taylor

This event is a question-and-answer session that focuses on sexual selection, involving symposium speakers Brennan, Johnson, Clark, Laidre, and Taylor.

65-11 Riddell, EA*; Mutanen, M; Ghalambor, CK; Iowa State University, University of Oulu, Colorado State University; *riddell.eric@gmail.com*

Sensitivity of thermal tolerance to precipitation and humidity in a high-latitude click beetle

Species' thermal tolerances are used to estimate vulnerability to climate warming, but few studies consider the role of the hydric environment in shaping physiological responses to warming. As environments become hotter and drier, organisms respond by limiting water loss to lower the risk of desiccation; however, reducing water loss may produce trade-offs that lower thermal tolerances if respiration becomes inhibited. Here, we measured the sensitivity of evaporative water loss (EWL) and critical thermal maximum (CT_{max}) to humidity in response to short term changes in precipitation. We collected click beetles (Elateridae) near Oulu, Finland from two sites that were sampled immediately after rain and several days after rain. In the laboratory, we acclimated beetles to wet or dry humidity treatments (30%, 50% relative humidity), and then performed thermal tolerances experiments that measured EWL and CT_{max} at two different acute humidity conditions (wet and dry) in a fully balanced experimental design. Click beetles sampled immediately after rain events had a significantly higher CT_{max} and EWL than beetles measured several days after rain. Analysis of covariance indicated that EWL was negatively associated with CT_{max},

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such that individuals with high EWL exhibited a lower CT_{max}. We found a significant interaction between the acclimation and acute humidity treatments, indicating a high degree of plasticity in CT_{max} over times scales ranging from minutes to days. The correlation between EWL and CT_{max} identifies the need to study thermal tolerances from an 'whole-organism' perspective that considers trade-offs between physiological traits. Moreover, our experiments revealed a high degree of plasticity that complicates CT_{max} as a straightforward proxy of climate vulnerability.

83-7 Ridgway, MR*; Tunnah, L; Bernier, NJ; Wright, PA; Department of Integrative Biology, University of Guelph; *mridgway@uoguelph.ca*
How does an amphibious fish osmoregulate without gills?
Gills are the primary site of ionoregulation for most fishes. However, amphibious fishes experience diminished gill function during terrestrial sojourns due to a lack of water flow over the gills. Some amphibious species use cutaneous ionocytes for ion exchange. Previous work has shown an increase in the size and number of skin ionocytes during air-exposure in the amphibious mangrove rivulus (*Kryptolebias marmoratus*), presumably to maintain ion-balance. However, the factors regulating ionocyte remodelling during air-exposure were unknown. Using *K. marmoratus* as a model, and metyrapone as a pharmacological inhibitor of cortisol synthesis, we tested the hypothesis that cortisol regulates ionocyte remodeling and hydromineral balance during the transition of amphibious fishes from water to land. Our data show that the transition from water to air induces a rapid (within 5 minutes), robust (10-fold), and transient (maintained for the first 24 h in air, but subsequently return to resting levels by 7 days) increase in whole-body cortisol levels, and that exposure to metyrapone completely inhibits the rise in cortisol without impacting survival. We measured the morphometrics of skin ionocytes and found that a fish's ability to mount a cortisol response significantly impacts their capacity for skin ionocyte remodeling. Following air-exposure, we also observed that a subset of skin ionocytes in each fish were of a novel morphology, with an irregular shape and multiple processes. Thus, cortisol plays a similar role in the skin of *K. marmoratus* as it does in the gills of fish moving from freshwater to seawater. Further studies are needed to determine if

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cortisol's role in skin remodeling is universal in amphibious fishes.

43-9 Riley, AK*; Grindstaff, JL; Oklahoma State University; *agoffri@okstate.edu*

The effects of paternal deprivation on stress-induced corticosterone levels of zebra finch offspring

Maternal removal causes abnormal levels of fearfulness, antisocial behaviors, and learning, deficits in mammalian and avian offspring. In particular, zebra finches (*Taeniopygia guttata*) that experience maternal removal exhibit hyper-responsive hypothalamic-pituitary-adrenal (HPA) axis function. Around 80% of all bird species, including zebra finches, provide bi-parental care. Despite this, there have been few studies testing the effects of paternal removal on offspring. We set up groups of birds that experienced father removal at hatching, father removal at fledging, and a control group where both parents were present. Once mature, we obtained offspring baseline corticosterone through blood sampling. A week later, we subjected the same birds to a social isolation challenge and immediately took blood samples to obtain their stress-induced corticosterone levels. We predict that there will be no difference in baseline corticosterone levels between groups. We also predict that birds that experience paternal removal at hatching and at fledging will have higher stress-induced corticosterone levels in comparison to control birds. This study will help further our understanding in the significance of paternal care on the development of a normal stress response.

40-2 Riordan, KC*; Levin, E; Thometz, NM; Batac, F; Liwanag, HEM; California Polytechnic State University, San Luis Obispo, CA, University of San Francisco, San Francisco, CA, Office of Spill Prevention and Response, California Department of Fish and Wildlife, Santa Cruz, CA; *kriord01@calpoly.edu*

The morphology and thermal function of sea otter pelts across ontogeny

Sea otters (*Enhydra lutris*) are unique among marine mammals in that they lack blubber and instead must rely on especially thick fur to keep warm in the marine environment. Despite a wealth of knowledge

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regarding the functional morphology of the adult pelage, almost nothing is known about the characteristics of lanugo (newborn pelage). To better understand the characteristics of sea otter fur across ontogeny, we investigated the morphology and thermal function of otter pelts (n=39) across six age classes: neonates, small pups, large pups, juveniles, subadults, adults. Guard hair length and hair circularity were collected for morphological analysis. Thermal conductivity and thermal resistance were measured to determine thermal function of pelts. Neonates and small pups had longer guard hairs compared to older age classes ($p<0.001$), consistent with the timing of the molt of the lanugo and growth of more adult-like pelage. Guard hair circularity showed no differences across age classes ($p=0.86$), suggesting the flatness of the guard hairs may be a relatively conserved characteristic across ontogeny. The neonatal pelage had a higher thermal conductivity in air ($p<0.001$) compared to the juvenile, subadult, and adult pelage, suggesting lanugo pelts are poorer insulators. However, thermal resistance did not differ across age classes ($p=0.612$), as the greater thickness of the lanugo pelage compensated for the higher thermal conductivity. Future work will determine fur density using histological methods and measure thermal function of pelts in water. This study is the first to investigate the functional morphology of sea otter lanugo, and will connect the fur structure to its thermal function.

32-3 Rippe, JP*; Moreland, KN; Baumann, JH; Aichelman, HE; Castillo, KD; Davies, SW; Matz, MV; University of Texas at Austin, Austin, TX, Bowdoin College, Brunswick, ME, Boston University, Boston, MA, University of North Carolina at Chapel Hill, Chapel Hill, NC; *jpr6mg@gmail.com*

Coral connectivity on the Belize Barrier Reef: Water clarity, not temperature, drives genetic differentiation in Siderastrea siderea

Ocean warming is often implicated in the widespread demise of coral reefs, as high temperatures can lead to a breakdown of the relationship between coral hosts and their algal symbionts. However, recent research has revealed that the effects of warming on corals of the same species may vary widely depending on their thermal history. Specifically, corals from nearshore habitats, which experience relatively extreme daily and seasonal temperature

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fluctuations, have demonstrated higher tolerance than those which experience more thermally stable conditions. Importantly, this variation in thermal tolerance has been shown to be heritable, implying that genetic linkage between resilient nearshore and sensitive forereef populations could foster reef-scale adaptation to warming. Here, we use 2bRAD sequencing to explore the population genomics of the massive starlet coral, *Siderastrea siderea*, throughout the Belize Barrier Reef. 142 colonies of *S. siderea* were sampled across five pairs of nearshore and forereef sites. These sites were intentionally selected based on their distinct thermal characteristics, where nearshore sites experience both warmer and more variable temperature conditions than those on the forereef. However, we find that populations on this reef are not in fact differentiated based on these thermal regimes, but rather by light availability. This result suggests that for *S. siderea*, one of the few species that has shown resilience to ocean warming trends, water quality may in fact be a more important selective force than temperature variation, at least at the regional scale.

108-6 Ritchie, MW*; Dawson, JW; MacMillan, HA; Carleton University ; *marshallritchie@cmail.carleton.ca*

A simple and dynamic thermal gradient device for measuring thermal performance in small ectotherms

Ectotherm performance and fitness are heavily dependent on environmental temperature. Laboratory exposure to favorable and unfavorable temperatures is used to study these effects, as well as the physiological, biochemical, and molecular underpinnings of variation in thermal performance in many small ectotherms (e.g., insects). It can be challenging, however, to create and manipulate several dynamic thermal environments concurrently in a laboratory setting. Here, we describe the creation and use of a thermal gradient device that can produce a wide range of temperatures that change over time. This device is composed of a solid aluminum plate and copper tubing, combined with a pair of programmable refrigerated circulator baths. This approach avoids the use of multiple heating/cooling baths and makes thermal experiments (e.g., creating a thermal performance or survival curves, quantifying responses to fluctuating thermal environments, or monitoring insect behaviour across a range of temperatures) easier, faster, and more

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cost-effective. As a proof-of-concept, we used the thermal gradient device to produce a low-temperature survival curve for *Drosophila melanogaster* in a single experimental run and measured the growth rate of crickets (*Gryllodes sigillatus*) across a range of temperatures over days at varying amplitudes.

106-2 Rivera, HE*; Williams, LM; Gilmore, TD; Davies, SW; Boston University , Boston University; *hrivera@bu.edu*

Differential regulation of innate immunity between symbiotic states in a facultative coral

Many cnidarians, including reef-building corals, establish symbiotic relationships with photosynthetic algae of the family Symbiodiniaceae. Previous studies have implicated host innate immunity as playing a role in the maintenance of cnidarian-algal symbiosis and it has been shown that establishing symbiosis with different genera of algal symbionts modulates thermal tolerance. Using the facultatively symbiotic coral, *Oculina arbuscula* we investigated how host immunity, in particular NF-KB expression, was modulated in the presence and absence of intracellular algal symbionts. We used menthol to induce symbiont expulsion to generate aposymbiotic and symbiotic fragments of the same coral genet. We then assayed NF-KB protein levels through Western blotting and compared protein levels between symbiotic states. We relate these findings to our prior transcriptomic profiling of symbiotic and aposymbiotic branches of colonies of the same species and contrast patterns across other taxa that host intracellular photosymbionts including the anemone *Aiptasia*, the sponge *Cliona*, and the salamander *Ambystoma*. Our results shed new light on the mechanisms that govern healthy symbiosis with Symbiodiniaceae. As heat-induced bleaching threatens corals across the world, there is an urgent need to understand how these partnerships will respond to changing environmental conditions.

28-10 Rivera, JA*; Fuentes-G., JA; Martins, EP; Arizona State University, Tempe, University of Alabama, Tuscaloosa; *jriver58@asu.edu*

Head shape is constrained by body size and sexually selected traits in Sceloporus lizards

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The vertebrate skull is a complex structure that has been shaped over evolutionary time by competing selective forces. Here, we take a comparative approach to study how male skull shape varies in the diverse lizard clade, *Sceloporus*. Specifically, we used CT scans, geometric morphometrics, and phylogenetic comparative methods to compare the skull shapes of species that differ in body size and the presence of ventral coloration, a key communication trait of *Sceloporus* lizards. We found that males of smaller-bodied species possess elongated and narrow skulls with shallower snouts than do males of larger-bodied species, which possess shorter and more robust skulls. Additionally, we found that males of species with colorful ventral patches have larger and more robust skulls than do males of species that have lost the ventral patches over evolutionary time. Males with white bellies have elongated and narrow skulls. Our phylogenetic analyses infer larger body size optima for males of species that possess ventral coloration than those of species that have lost the ventral patch. By taking advantage of imaging technology and placing it in a comparative framework, we gain new insight on the evolutionary processes that shape phenotypic traits leading to the patterns of diversity seen today.

76-5 Rivest, EB*; Song, B; Audemard, C; Carnegie, RB; Virginia Institute of Marine Science, Gloucester Point, VA; *ebrivest@vims.edu*

Interactions between oyster physiology and microbiome are influenced by seasonal baselines and water manipulations

The deterioration of water quality in Chesapeake Bay during the summer is a suspected cause of mortality events of cultured oyster larvae. Relative contributions of abiotic stressors (e.g. temperature) and biotic stressors (e.g. harmful algae blooms) are currently unknown. Stressors directly impact larval physiology, and larval health can also be influenced by effects on the larval microbiome. We examined the effects of water quality on larval physiology coincident with effects on microbiomes associated with larvae and culture water. To evaluate the relative role of seasonal shifts in abiotic water quality, we replicated culturing experiments in May, June, and July, 2018. To manipulate the microbiomes available to inoculate oyster embryos, we raised larvae

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under three treatments: sand-filtered water (MECH), sand-filtered and UV-treated water (STD), and STD water 'seeded' with adult oyster microbiome (OJ). Larvae in OJ exhibited the lowest survival, but the growth of surviving larvae was similar among treatments. Larval metabolism differed among treatments, whose relative influence depended on the time of season. Analysis of 16S rRNA gene sequences revealed seasonal variation in larval microbiomes, but not in water microbiomes. The relative effects of treatments on larval microbiomes varied across the season. Microbial taxa associated with larval physiology will be presented. The results of this large collaborative project provide important insight not only on interactions between larval physiology and microbiome, but also on a vexing problem facing the shellfish aquaculture community: the difficulty of overcoming limitations, of uncertain cause, to hatchery production.

103-6 Rizwan, M*; Spence, M; Rull, M; Konow, N; Albert, A; Panessiti, C; University of Massachusetts Lowell; *maya_rizwan@student.uml.edu*

Changes in sternohyoid contraction pattern with terrestrialization in the axolotl

The Axolotl (Ambystoma mexicanum) can be induced with thyroxine hormone to undergo metamorphosis, resulting in physiological and anatomical changes that enable terrestrialization. As the Axolotl's feeding morphology changes, feeding kinematics are also expected to change, but past research has been mostly limited to studying external feeding kinematics. We sought to determine if contraction of sternohyoid (SH), one of the main muscles involved in feeding, and an important linkage between the feeding apparatus and the body musculature, changes across terrestrialization. Shortening of SH expands the buccal cavity in animals by lowering and retracting the hyoid, and can also aid in gape opening, whereas shortening of the hypaxial musculature may lengthen SH. We hypothesized that SH would undergo active lengthening in water during strikes, a gape-expansive behavior, due to the drag imposed on skull expansion by the dense fluid medium. Therefore, SH length-changes during strike were expected to be greater during gape opening than closing, in both aquatic and terrestrial Axolotls. We implanted SH with radio-opaque markers and recorded 3D videofluoroscopy data of feeding

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before and after terrestrialization. Peak SH lengthening occurred as the mouth was opened in both aquatic and terrestrial axolotls. Peak shortening of sternohyoid occurred during gape closing as the tongue was being retracted. The difference between mean SH shortening in terrestrial versus aquatic feeding was only 2%, compared to a 35% difference in lengthening. These results support our hypothesis of SH contraction changing with terrestrialization, and broaden our understanding of the challenges associated with terrestrialization and the evolution of feeding systems.

S2-10 Roberts, SR; University of Washington, School of Aquatic and Fishery Sciences, Seattle, WA; *sr320@uw.edu*

A perspective on DNA methylation in bivalves

The function of DNA methylation in shellfish where the limited amount of DNA methylation is predominantly found in gene bodies is not completely understood. One explanation is that the role of gene body DNA methylation is dependent on gene function, a potential phenomenon that has arisen from selective pressure on lineage-specific life history traits. We know that in other taxa epigenetic marks are associated with phenotypes independent of genetic variation, the environment can influence DNA methylation, and epigenetic marks can be inherited. While we have examined DNA methylation in bivalves for almost a decade, there is still not convincing evidence that the function(s) align with some of the early hypotheses. It has also been suggested that DNA methylation might not have a biological function. DNA methylation landscapes will be described in bivalves and specific data sets will be presented including looking at the role of DNA methylation in genomic regulatory function and heredity in oysters. In addition, perspectives will be provided on how to address the function of epigenetic mechanisms in mollusks.

59-9 Roberts, EA*; Gilman, SE; The Keck Science Department, Claremont McKenna College, The Keck Science Department, Scripps College; *eroberts@cmc.edu*

Simulated ocean and aerial warming have opposing effects on the growth of the barnacle, B. glandula: An energy budget model approach

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Predicting responses of intertidal species to changes in ocean and air temperatures requires an understanding of how thermal stress alters organismal physiology and energy budgets. Intertidal organisms are unique in experiencing two distinct thermal environments daily, with the oscillation of tides, and it is not clear whether changes in air and water temperature influence intertidal species in similar ways. We used a Scope for Growth (SFG) framework to quantify the effects of warming air and water temperatures for a population of the intertidal barnacle *Balanus glandula* from Friday Harbor, WA. *B. glandula* is a sessile crustacean common to the upper intertidal of the northeastern Pacific, from Alaska to Mexico. We developed the SFG model from a field study of barnacle growth in combination with laboratory measurements of the effect of temperature on *B. glandula's* feeding rate, aquatic respiration, aerial respiration, and recovery from aerial exposure. We estimated energy intake from the relationship between tissue growth and estimated temperature and size-dependent feeding and costs. Net energy balance was not significantly greater than zero for adult B. glandula in both the upper and mid intertidal. Simulated increased air temperatures caused the energy balance to decrease, while increased water temperature increased the energy balance. Our results suggest that, at least in the northern part of its range, *B. glandula's* growth is limited by cold water temperatures, and that even modest ocean warming could ameliorate the negative effects of increasing body temperatures at low tide.

59-5 Roberts, KT*; Rank, NE; Dahlhoff, EP; Stillman, JH; Williams, CM; University of California, Berkeley, Sonoma State University, Santa Clara University; *kevrob@berkeley.edu*

Snow modulates winter energy use and cold stress across an elevation gradient in a montane ectotherm

Snow cover insulates soil-dwelling organisms from both warm and cold air temperature extremes, altering cold stress and energy use over winter. As climate change alters both snow cover and air temperatures, it is critical that we account for the role of snow in modulating winter stresses on soil-dwelling organisms. The importance of snow will change along environmental gradients; along ascending elevational gradients, air temperatures decrease while

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snow cover extent and duration increase. We explore how snow modulates cold and energy stress on a montane beetle, *Chrysomela aeneicollis*, along replicated mountain transects in the Sierra Nevada Mountains in the Western United States. Ecophysiological models, driven by long-term microclimate data in five replicated elevational transects, showed that energy use decreases as elevation increases, and that this effect is more pronounced in snowy winters. Mid-elevation habitats are the coldest, and that this effect is amplified in dry winters. This suggests that decreased winter snow cover will lessen the energetic cost of dormancy in low elevation habitats, while intermediate elevation habitats will be most negatively impacted by declining snowpack due to increased cold exposure. High elevation habitats have relatively stable conditions regardless of the amount of winter snow cover and may be able to provide refugia as drier winters become more common.

58-5 Robin, AN*; Nonacs, P; University of California, Los Angeles; *robina@ucla.edu*

The presence of others may shape the economic decision making of a food-storing arboreal squirrel

Food-storing awards individuals' greater control over their survival by distributing collected resources across periods of scarcity. One problem imposed upon animals engaging in food storage is deciding what items are best stored and which are best consumed immediately. For non-hibernating arboreal squirrels, making thousands of these eat-cache decisions accurately and efficiently is critical for survival. The choice to eat or cache has been shown to be influenced by a multitude of factors including seed size, fat content, and tannin levels. Here, we explore how items with future value (e.g. storable food) versus items with only immediate value (e.g. cannot be stored) may shift in relation to the presence of others in the foraging patch. Hetero- and conspecifics may introduce competition for resources, present added mating opportunities, or pose a potential danger that may shift the importance of caching or immediately consuming a food item. Moreover, the presence of others may be an especially pertinent factor in the decision to eat or cache because each animal present has the potential to plunder stored items. Scatter-hoarding squirrels have been shown to adjust their caching related behaviors

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in response to conspecifics by employing evasive digging tactics. It is less clear, however, how the presence of other squirrels, as well as, animals of other species may shift the decision to cache or eat an item. We are measuring how the number of individuals present at an artificial foraging patch and species composition of those individuals influences a western grey squirrel's (Sciurus griseus) preference for a storable versus non-storable food item. Further, we relate these preferences to body condition and between-individual variation in several personality traits.

62-2 Robinson, HE*; Alexander, JD; Bartholomew, JL; Hallett, SL; Hetrick, NJ; Perry, RW; Som, NA; Humboldt State University, Arcata CA, Oregon State University, Corvalis OR, US Fish and Wildlife Service, Arcata CA, US Geological Survey, Cook WA, US Fish and Wildlife Service and Humboldt State University, Arcata CA; *hr573@humboldt.edu*

Simulating disease risk for juvenile salmonids using a mechanistic framework to model the spring density of the parasite Ceratonova shasta

The myxozoan parasite *Ceratonova shasta* is linked to low survival rates of juvenile salmonids. This parasite is endemic to the Pacific Northwest, and alternates between salmonid and annelid hosts as waterborne spore phases. In the Klamath River (CA), dams have created an "infectious zone" of elevated parasite density by limiting upstream passage of anadromous fishes that concentrates spawning and co-occurs with habitat suitable for annelids. The density of *C. shasta* spores is typically highest in the spring (March-June) when juvenile salmonids outmigrate through the infectious zone. Management approaches aim to disrupt the parasite's lifecycle as abundance of spores directly influences disease risk for juvenile salmonids. Predicting spore density can be used to assess the impact of proposed management actions and to support existing tools that estimate population dynamics and disease-induced mortality of outmigrating salmon. We developed a model to predict the spring density of the parasite using both mechanistic (process-based) and statistical (correlative) relationships. The model captures seasonal features of *C. shasta* such as the initial detection of the parasite in the spring, temporal variability, and peak density. Using a mechanistic

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framework encapsulates the complex lifecycle and transmission dynamics for this aquatic parasite, and includes environmental parameters that are sensitive to management decisions. The predictive model can be used to evaluate the impact of future scenarios such as dam removal and climate change on disease risk.

38-11 Robles Martinez, D*; Sustaita, D; California State University San Marcos; *roble055@cougars.csusm.edu*

Geometric morphometric analysis of foot pad shape of salt marsh harvest mice and co-occurring rodents in the Suisun Marsh, California

Differences in the foot morphology among species with different locomotion strategies have been previously described for the order Rodentia. In this study we used geometric morphometric analysis to compare the palmar and plantar pad configurations of salt marsh harvest mice (SMHM) and co-occurring rodents in Suisun Marsh, California. We hypothesized the SMHM would exhibit shorter and wider configurations for both palmar and plantar pads compared to co-occurring rodent species. This configuration type should provide greater contact surface for frictional support on vertical substrates which the SMHM uses to escape inundation. Preliminary Procrustes ANOVA analyses based on n=20 individuals indicated significant differences in plantar pad, but not palmar pad, configurations among species after controlling for allometry. However, the differences were contrary to what we hypothesized, in that SMHM plantar pads were relatively narrow and elongated compared to those of the California voles and house mice. Species appeared to group more by phylogeny in plantar pad shape morphospace, and more by locomotor behavior in palmar pad shape morphospace, suggesting some degree of independence in their potential responses to selective pressures. These preliminary results provide a foundation for investigating the specific role of foot pad shape in the locomotor performance of these species in their wetland habitat.

35-10 Rohrer, KN*; Ferkin, MH; University of Memphis; *knrohrer@memphis.edu*

Influences on nest and latrine decision-making in meadow voles

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Nest and latrine location choice can be a critical part of territory establishment. How animals determine a suitable place to live is dependent on many factors, one of which is their own natal habitat. Natal habitat preference induction (NHPI) predicts that animals either are selected by their habitat to prefer that habitat or that cues of the natal habitat are used to find similar habitats after dispersal. We extend NHPI to include how an animal uses and organizes its surroundings as well as site choice. We tracked the nest and latrine locations of meadow voles (*Microtus pennsylvanicus*) across several weeks to determine consistency of a vole's choice and if there were siblings made similar choices. Then we tracked the nest and latrine locations of pregnant voles and their subsequent offspring to determine the impact on maternal nest and latrine placement on these choices. An individual's choices were repeatable for nest (0.23) and latrines (0.27). Heritability of the behaviors was also considered. Broad-sense heritability was high (0.5-0.6), but narrow-sense heritability was comparable to other species nest-building behaviors (0.2). Nest construction also significantly declined as voles aged. A lack of effect of the maternal location choices on offspring location choices suggests a high degree of environmental or social effects on nest and latrine location choices. This may allow a greater diversity in how a habitat is used by different generations of meadow vole families.

BSP-7-6 Rojas, M*; Chan, KYK; Swarthmore College; *mrojas1@swarthmore.edu*

Environmental predictability: a missing link in ocean acidification sensitivity research

While ocean acidification (OA) has broadly negative effects on a significant number of marine organisms, their responses are highly variable and could be a reflection of local adaptation. Coastal organisms, in particular, routinely experience pH fluctuations greater than the predicted 0.3-0.4 pH unit decrease in mean global pH by 2100 due to significant seasonal, tidal and diel cycles in seawater carbonate chemistry. These fluctuations are expected to increase in their unpredictability, magnitude and frequency as atmospheric CO2 levels continue to rise. Here, we conduct a meta-analysis of the responses to OA for over 100 species of the economically and ecologically important echinoderm and compare the

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observed vulnerability against long-term oceanographic carbonate chemistry data at the collection location. pH fluctuations are common around the globe with both longer term seasonal trends and short term autocorrelated patterns. The geospatial pattern of predictability varies with upwelling and latitude. In addition to between order differences in OA sensitivity, there was also a negative relationship between organismal OA sensitivity and increasing predictability in the frequency and magnitude of pH fluctuations in the organismal location of origin. Our work suggests that organismal responses to future ocean conditions are limited by both their evolutionary history and current local environmental conditions.

39-11 Rolfe, SM*; Porto, A; Pieper, S; Winchester, J; Boyer, D; Summers, A; Maga, AM; University of Washington, Seattle and Seattle Children's Research Institute, WA, Seattle Children's Research Institute, WA, Isomics, Inc, Duke University, Durham, NC, University of Washington, Seattle ; *smrolfe@uw.edu*

SlicerMorph: A toolkit for morphometric analysis of high-resolution specimen data

Recent advances in 3D imaging have driven collaborative, "big data" initiatives, such as *#scanallfish* and *oVert*, with the goal of making data broadly accessible to the organismal biology community. Data from these projects is shared via public repositories like MorphoSource, encouraging data reuse and removing obstacles posed by access to imaging equipment. As quantitative imaging becomes more widely available, there is a corresponding need for image analysis software that supports open, reproducible research. Open-source, community-driven platforms, such as 3D Slicer, provide a compelling solution to the challenges around publishing and maintaining accessible toolkits and workflows. We have developed SlicerMorph, an extension to the 3D Slicer platform that provides users with modules to support analysis of 3D organismal forms, including conducting geometric morphometric analysis using both landmark-driven and landmark-free approaches, annotation of 3D curves and patch-based landmarks, as well as convenience modules for 3D data retrieval, import and export. We aim to establish a community around SlicerMorph to support collaboration, sharing of data and methods, and sustainable tool

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development. To this end, we hold regular short courses, conduct online user meetings, and provide tutorial material. In this talk, I will address how SlicerMorph addresses challenges specific to morphometric analyses of high-resolution specimen data and highlight common workflows from data import from public repositories through visualization of statistical shape analysis and export of 3D animations.

85-2 Romanovich, LA*; Rade, RG; Fetcher, N; Voltzow, J; University of New England, Biddeford, ME, University of Scranton, PA, Wilkes University, Wilkes Barre, PA; *lromanovich@une.edu*

Symbiosis in the time of climate change: Bleaching of Exaiptasia pallida in response to concurrent warming and acidification

Many cnidarians live in obligate symbiosis with photosynthetic dinoflagellates of the family Symbiodiniaceae. The introduction of environmental stressors associated with climate change, including ocean warming and ocean acidification, has an impact on this relationship and may initiate the bleaching response in which the host expels the symbionts. Using symbiotic *Exaiptasia pallida* as a model organism in which to study this association, we looked at the effects of projected future ocean conditions on the bleaching response. We designed a factorial experimental system in which anemones were placed in one of four treatments: (1) current ocean conditions at 28° C and pH 8.2; (2) future warming conditions at 33° C with current pH 8.2; (3) future acidification conditions at pH 7.8 with current temperature 28° C; and (4) future ocean conditions at 33° C and pH 7.8. We monitored the health of the symbiosis during exposure using fluorescence microscopy and chlorophyll fluorometry. We also assessed the final symbiont density in each anemone after 2 weeks in experimental conditions. Anemones exposed only to acidification did not lose symbionts and maintained a symbiosis equal to those maintained in the current oceanic conditions. Anemones in warmed waters and in the warmed plus acidified waters underwent bleaching to similar extents. We suggest that there is an interaction between the two factors' effects on the rate of symbiont loss and change in chlorophyll fluorometry of *in hospite* symbionts. Thus it is important to evaluate the interactions of multiple stressors when trying to determine how organisms will respond to climate change.

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96-12 Romero-Diaz, C*; Xu, C; Campos, SM; Kusumi, K; Hews, DK; Martins, EP; Arizona State University, Tempe, AZ, Georgia State University, Atlanta, GA, Indiana State University, Terre Haute, IN; *cromerod@asu.edu*

Brain transcriptomic responses of Yarrow's spiny lizard, Sceloporus jarrovii, to conspecific visual or chemical signals

Species with multimodal communication integrate information from social cues in different modalities into behavioral responses that are mediated by changes in gene expression in the brain. However, the neuromolecular basis of behavior remains poorly understood. Here, we use RNA-Seq to analyze brain transcriptome responses to either chemical or visual social signals in a territorial lizard with multimodal communication. Using an intruder challenge paradigm, we exposed 18 wild-caught, adult, male *Sceloporus jarrovii* to either male conspecific scents (femoral gland secretions), the species-specific push-up display (a programmed robotic model), or a control (an unscented pebble). We conducted differential expression analysis with the reference genome of a closely related species, *S. undulatus*. Despite the large inter-individual variation, we found significant differences in gene expression in the brain across signal modalities and the control. The most notable differences occurred between chemical and visual stimulus treatments, followed by the control vs. visual stimulus treatment. Altered expression profiles can explain aggression differences in the immediate behavioral response to conspecific signals from different modalities. Shared differentially expressed genes between visual- or chemical-stimulated males are involved in neural activity and neurodevelopment, and several other differentially expressed genes in stimulus-challenged males are involved in conserved signal-transduction pathways associated with the social stress response, aggression, and the response to territory intruders across vertebrates (e.g. NF-κB, MAPK).

BSP-4-1 Root, ZD*; Allen, C; Brewer, M; Gould, C; Medeiros, DM; University of Colorado Boulder; *zaro7315@colorado.edu*

Straw, sticks, and bricks: Genome duplication and the evolution of fibrillar collagens in the vertebrate musculoskeletal system

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Fibrillar collagens are a metazoan innovation that are a part of the extracellular matrix of muscle, skeleton, and other connective tissues. Comprised of three families of genes (Clade A, Clade B, Clade C), they underwent duplication and neofunctionalization in the jawed vertebrate lineage (gnathostomes). Previous work has suggested that ancestral chordates possessed only four fibrillar collagens (2A's, 1B, 1C) while most jawed vertebrates have eleven (5A's, 4B's, 2C's). The evolution of vertebrates from invertebrate chordates also coincided with morphological novelties, so we asked whether the duplication of fibrillar collagens was linked to the origin of these novel cell types. We used the jawless lamprey *Petromyzon marinus* to test this question, as they diverged from gnathostomes more than 500 million years ago and could thus provide insight into the stepwise evolutionary process in vertebrates. We discovered twelve fibrillar collagens in lamprey (6A's, 5B's, 1C) and were able to identify several lineage-specific duplications. Between lamprey and gnathostome orthologs, we found that lamprey collagens were less specific in the musculoskeletal system, being coexpressed more often in both muscle and skeleton. However, we found that some lamprey paralogs were subfunctionalized in lamprey-specific morphology like mucocartilage as well as the epi/hypobranchial musculature. Our results suggest that the last common ancestor of gnathostomes and lamprey had seven fibrillar collagens (3A's, 2B's, 2C's) with redundant expression across the musculoskeletal system. We also posit that some innovations to the gnathostome and lamprey muscle and skeleton may have been the result of collagen duplication and subfunctionalization.

83-2 Root, L*; Cnaani, A; Campo, A; MacNiven, L; Kültz, D; University of California, Davis, Agricultural Research Organization, Israel; *ltroot@ucdavis.edu*

A data-independent acquisition (DIA) assay library for quantitation of environmental effects on the kidney proteome of Oreochromis niloticus

Interactions of organisms with their environment are complex and regulation at different levels of biological organization from genotype to phenotype is often non-linear. While studies of transcriptome regulation are now common for many species, corresponding quantitative studies of environmental effects on

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proteomes are needed. Here we report the generation of a data-independent acquisition (DIA) assay library that enables simultaneous targeted proteomics of thousands of *O. niloticus* kidney proteins using a label- and gel-free workflow that is well suited for ecologically relevant field samples. Transcript and protein abundance differences in kidneys of tilapia acclimated to freshwater and brackish water (25 g/kg) were correlated for 2114 unique genes. A high degree of non-linearity in salinity-dependent regulation of transcriptomes and proteomes was revealed, demonstrating the complementary nature of the DIA assay library approach and suggesting that the regulation of *O. niloticus* renal function by environmental salinity relies heavily on post-transcriptional mechanisms. In addition to significance testing, the application of functional enrichment analyses using STRING and KEGG to DIA assay datasets identified *myo*-inositol metabolism, antioxidant and xenobiotic functions, and signaling mechanisms as key elements controlled by salinity in tilapia kidneys. In conclusion, this study presents an innovative approach for targeted quantitative proteomics used to identify proteins and biological processes that are regulated non-linearly at mRNA and protein levels during a change of environmental salinity. Funded by NSF grant IOS‐1656371, BARD, and AES projects CA-D-ASC-7690-H and CA-D-ASC-7624RR

BSP-10-1 Rosales, K*; Edsinger, E; Salk Institute; *krosales@salk.edu*

Comparative analysis of cephalopod mitochondrial genomes reveals rapid sequence convergence across replicated genes or control regions within individuals

Newly replicated regions in genomes typically diverge in sequence over time, as random mutations accumulate and differential functions and selective pressures arise. Concerted sequence evolution in nuclear genomes occurs but is uncommon. Interestingly, mitochondrial genomes in several animal groups have duplicate or triplicate control regions or genes that undergo highly rapid concerted evolution and maintain nearly 100% sequence identity, including in seabirds, fishes, and cephalopods. These occurrences are poorly understood and are exceptional: 1) mitochondrial genomes generally lack replicate features despite many likely genome

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duplication events that give rise to gene rearrangements in diverse animals, 2) control regions generally evolve rapidly between individuals, making maintenance of sequence identity between paralogs that much more challenging, if not a contradiction, and 3) convergent sequence evolution in nuclear genomes is maintained by recombination but it is rare in mitochondrial genomes, suggesting possibly novel mechanisms at play. Here, we assess all available mitochondrial genomes in cephalopods using synteny and phylogenetic methods, and include for the first time comparisons between individuals within species. Like previous studies, we find independent evolution of replicate control regions in cuttlefish, oegospid squid, and loliginid squid, and duplicated genes in oegospid squid. Sequences were up to 100% identical at paralogous loci within an individual but divergent for orthologs between individuals. These findings highlight a tension of sequence convergence within but divergence between individuals, and raise as questions for future studies, how and where in the lifecycle and anatomy does convergence vs. divergence occur?

BSP-2-2 Ross, SA*; Dominguez, S; Nigam, N; Wakeling, JM; Simon Fraser University, Burnaby, BC; *saross@sfu.ca*

The effects of skeletal muscle size on the tissue energy distribution and work output of 3D muscle during cyclic contractions

Skeletal muscles are typically considered and modelled as massless and one-dimensional. Yet studies have shown that tissue mass and the three-dimensional (3D) structure of muscle alter contractile behaviour during cyclic contractions; however, it is not yet known how these factors affect the distribution of energy through contracting whole muscle. Therefore, in this study we examined how energy is distributed through muscle tissue during cyclic contractions, and how this is altered by changes in kinetic energy across pennate muscles of different mass. To do this, we simulated cyclic contraction regimes of a three-dimensional finite element model of pennate muscle and varied the size and architecture of the muscle model. We also qualitatively validated the model by comparing its behaviour to that of in situ muscle during analogous experimental trials. We found that greater muscle mass resulted in relatively more mass-specific energy stored as kinetic energy

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during the simulated contraction cycles, and this was associated with lower mass-specific mechanical work output per cycle. Simulated muscles with higher initial pennation angles showed smaller reductions in mass-specific work with greater muscle mass compared to muscles with lower initial pennations. We additionally found that greater muscle mass and higher cycle strain amplitude led to greater reductions in maximum acceleration near the middle of the muscle tissue compared to at the moving end for both the simulated and experimental contractions. These results show that muscle tissue mass is an important determinant of 3D whole muscle behaviour during cyclic contractions.

57-2 Rossi, G*; Labbé, D; Wright, P; University of Guelph, Department of Integrative Biology, Guelph, ON; *grossi@uoguelph.ca*
Use it or lose it: The impact of prolonged darkness and air exposure on the visual system of an amphibious fish
The visual system of fishes is highly energetically expensive, both while processing information and at rest. Indeed, fishes living in permanent darkness often have visual structures that are reduced or absent altogether. Many other fishes experience periods of prolonged darkness throughout life (e.g. during estivation), yet the impact on their visual system is unclear. We used an amphibious killifish (*Kryptolebias marmoratus*) that occupies dark terrestrial habitats (e.g. rotting logs) during seasonal droughts to test the hypotheses that 1) exposure to prolonged darkness during air-exposure diminishes visual acuity and in turn, impairs hunting ability upon return to water, and 2) diminished visual acuity results from a reduction the size of the optic tectum (OT). We performed 3 week acclimations with a 2x2 factorial design, in which fish were either acclimated to a 12:12 or 0:24 light:dark photoperiod in water or in air. We then measured the optokinetic reflex in water as an estimate of visual acuity, hunting performance (i.e. the ability to leap out of water and capture terrestrial prey), and the size of the OT. In support of our hypothesis, we found that fish held in water had reduced visual acuity when acclimated to the dark, although fish held in air had poorer vision when returned to water regardless of photoperiod. The hunting performance of *K. marmoratus* followed a similar trend, suggesting that good vision is important for effectively hunting

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terrestrial prey. Changes in visual acuity did not result from an altered OT size because the OT did not differ in size between groups. Overall, our findings indicate that periods of prolonged darkness and air-exposure can impair vision in amphibious fish, as well as their ability to perform important visually demanding tasks.

89-7 Rosso, AA*; Logan, ML; McMillan, WO; Cox , CL; Georgia Southern University, University of Nevada Reno, Smithsonian Tropical Research Institute, Florida International University; *arosso@georgiasouthern.edu*

Both gene expression and physiology respond plasticity to thermal stress in a tropical forest lizard

Tropical ectotherms are thought to be especially vulnerable to climate change because many live in closed-canopy forests, which provide homogenous thermal landscapes that prevent behavioral buffering of stressfully warm temperatures, and most have narrow thermal tolerance ranges while living close to their upper thermal tolerance limits. Moreover, tropical ectotherms are thought to have decreased capacity for phenotypic plasticity because they have evolved in temporally stable thermal environments. We tested gene expression patterns and phenotypic plasticity of thermal traits in Panamanian slender anoles (*Anolis apletophallus*) by a) measuring changes in gene expression in response to short-term warming and cooling (two hours) and b) using a mesocosm experiment to measure phenotypic plasticity in response to long-term warming (one month). Many genes were differentially expressed in the brain, liver, and muscle in response to short-term warming, including genes that coded for heat shock proteins, and gene upregulation occurred primarily in response to warm conditions rather than cool conditions. During long-term warming, we found that lizards developed increased voluntary thermal maxima but displayed limited plasticity in thermoregulatory behavior in a laboratory thermal arena. Our results indicate that tropical forest lizards can use gene expression and phenotypic plasticity to respond to shifting environmental temperatures, and that these processes should be considered when predicting the future of tropical ectotherms under a changing climate.

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102-6 Roston, RA*; Mirando, AJ; McLellan, WA; Pabst, DA; Hilton, MJ; Roth, VL; University of Washington, Duke University, Duke University, UNC Wilmington, UNC Wilmington; *rroston@uw.edu*

Sutural structure in a telescoped skull: the maxillo-frontal suture in Tursiops truncatus

Sutures, the fibrous joints between bones, play important roles in the growth and mechanics of vertebrate skulls. Depending on their required mechanical function, sutures display different collagen fiber orientations and bone morphologies (e.g., abutting, interdigitated, beveled). Although in most mammals beveled sutures overlap only at the edges of skull bones, in cetaceans (whales, dolphins, and porpoises) bone overlap is so extensive that some sutures cover nearly the entire surface of the underlying bone. For example, the maxilla may overlap all but a narrow rim of the frontal bone. This extensive overlap, in conjunction with shortened maxillo-occipital distance, is commonly referred to as skull telescoping. The function(s) of skull telescoping are unknown but widely speculated, and include: relocating the nares to form a blowhole, aiding in echolocation, anchoring muscles of the nasal passage and blowhole, and counterbalancing the elongate rostrum. Despite widespread discussion of possible functions, the histological structure of overlapping cetacean sutures has received little attention. To inform investigations of functional hypotheses, we examined the maxillo-frontal suture in neonatal and adult bottlenose dolphins (*Tursiops truncatus*) using CT, microCT, and histological methods. In the neonates, the beveled interface was smooth and sutural fibers were oriented parallel to the bone margins, but in the adult, the maxilla and frontal were interlocked with rugose interdigitation of the bones and a complex arrangement of collagen fibers. This adult morphology suggests this suture forms a strong joint that resists complex mechanical loading.

56-12 Rowley, KM*; Morris, A; Bortoni, A; Young, I; Boerma, D; Breuer, K; Swartz, SM; Brown University, American Museum of Natural History; *kevin_rowley@brown.edu*

Evidence for a proximal-distal gradient in muscle responses to a wind gust perturbation in the Egyptian fruit bat

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Bats fly with remarkable maneuverability as they navigate dense colonies and turbulent air. When subjected to unilateral gust perturbations in the lab, bats recovered typical flight kinematics within one wingbeat. We investigated motor control strategies enabling rapid recovery by assessing left-right symmetry in the activation of a proximal vs. a distal wing muscle. Previous studies of recovery in terrestrial vertebrates showed recovery responses involved load-insensitive recruitment of proximal muscles and load-sensitive recruitment of distal muscles. We hypothesized this proximal-distal control gradient is conserved in bats, and we would observe symmetric activation of the pectoralis major, the primary flight motor and a proximal muscle, and asymmetric activation of the extensor carpi radialis longus (ECRL) muscle, a distal digit extensor in the forearm. We trained five *Rousettus aegyptiacus* to fly through a corridor, collecting bilateral intramuscular electromyography (EMG) using a wireless data logger. During some trials, subjects experienced an air jet (2.5x body weight) to one wing. The timing, amplitude, and between-side correlation of the EMG signal showed pectoralis recruitment was symmetrical in all trials. ECRL activation differed in amplitude between left and right wings during the perturbed but not control trials, demonstrating asymmetric, perturbation-dependent recruitment in this distal muscle. We conclude that proximal muscle recruitment in our model bat species is not altered by a significant perturbation to flight, while distal muscles are recruited in a manner dependent on external forces.

54-6 Rozen, J*; Rull, M; Spence, M; Konow, N; University of Massachusetts Lowell; *Joel_Rozen@student.uml.edu*

Contributions of hypaxial and sternohyoid muscles to hyoid depression in bichirs

Bichirs (f. Polypteridae) are the basal-most extant actinopterygians and studies of their feeding system may thus yield important insights into both the ancestral planform and the evolution of actinopterygian feeding mechanisms. In bichirs, as well as other gnathostomes, one of the functions of the sternohyoid muscle is to depress the hyoid and the mandible. The sternohyoid, along with the geniohyoid and hypaxials form a series of muscles that can either together or separately produce many kinematic

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outcomes, including hyoid depression. There is little literature examining how these muscles work together to produce vertical excursions of the hyoid in Actinopterygians, such as bichirs. We used biplanar x-ray videofluoroscopy to determine the relative contribution of the hypaxial and sternohyoid muscles to hyoid depression during chewing and food transport in bichirs. Our hypothesis was that the sternohyoid and hypaxial muscles contribute equally to hyoid depression. During phases of the intraoral feeding cycles where the hyoid was depressed 2.5 ± 1.4 mm (mean ± S.D.), the hypaxials lengthened by 0.2 ± 0.2 mm and the sternohyoid shortened by 0.2 ± 0.2 mm. When the hyoid was being elevated by 2.4 ± 1.13 mm, the hypaxials shortened by 0.2 ± 0.2 mm and the sternohyoid lengthened by 0.1 ± 0.2 mm. Our findings suggest that in bichirs, hyoid depression results from a combination of shortening of the sternohyoid and lengthening of the hypaxials, at odds with our hypothesis. It is possible that the sternohyoid acts as a connector for hypaxial and geniohyoid contractions; a hypothesis we are currently addressing. These data suggest that the ancestral condition for actinopterygians involves a complex interplay between hypaxial, suprahyoid and infrahyoid muscles in moving the hyoid during feeding.

18-1 Ruddy, BT*; Kirwan, DJ; Kajiura, SM; Porter, ME; Florida Atlantic University; *bruddy2018@fau.edu*

Collective swimming kinematics of Carcharhinus limbatus to Sphyrna mokarran during wild predation events

Schooling, or polarized collective movement, is hypothesized to provide increased predator awareness to individual fish. From lab experiments, swimming kinematics of prey are influenced by predator distance and neighbor interactions. Our goal was to examine distances among animals, excitation wave initiation, and swimming kinematics during wild predation events using the great hammerhead (*Sphyrna mokarran*; predator) and blacktip shark (*Carcharhinus limbatus*; prey). We predicted that individual blacktip sharks would initiate escape kinematic outputs in an excitation wave, or Trafalgar effect, that would propagate throughout the group starting nearest to the predator, and result in delayed initiation and decreased kinematic variables for individuals further. We used an aerial drone to capture footage of wild predation events (N=10)

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between blacktips and great hammerheads. Using Loggerpro motion tracking software, we calculated kinematic variables (peak to peak amplitude, tailbeat frequency, velocity, and whole-body curvature) of hammerheads and blacktips. ImageJ was used to quantify nearest-neighbor and prey-predator distances. Distance from the hammerhead was a significant effect in initiation of escape. When blacktips were within three body lengths of the hammerhead predator, we found increases in their body curvature, velocity, tailbeat frequency, and initiation of the Trafalgar effect. Within the excitation wave, blacktip sharks positioned closer to the hammerhead demonstrated increased values for body curvature, tailbeat frequency, and velocity compared to sharks further from the predator. These data show the Trafalfar effect is paired with changes in swimming kinematics that vary depending on distance from the predator in wild sharks.

39-7 Rueger, T*; Bardwaj, A; Turner, E; Buston, P; Boston University; *trueger@bu.edu*

Vertebrate growth plasticity in response to variation in a mutualistic interaction

Phenotypic plasticity, shaping responses according to environmental factors, is central to understanding the relationship between organism and their environment. Recent studies have shown that vertebrate growth can be plastic in response to biotic interactions such as competition and predation. It is unknown, however, if vertebrate growth plasticity occurs in response to mutualistic interactions. A good system to test this is the mutualism between anemonefish and anemone, since their sizes are often closely correlated. Here, we use a series of laboratory experiments and data from a wild population to test if the growth of clownfish, *Amphiprion percula*, is plastic in response to the size of their mutualistic partner. First, in the lab, we measured the growth of juvenile A. percula paired with surrogate anemone hosts, *Entacmea quadricolor*, of a range of sizes over 6 months. We found that fish in larger anemones grew faster than fish in smaller anemones, even though they received the same food rations. Next, we will repeat the experiment using fake anemones to test if the growth response is due to habitat area alone or if other components of the mutualism trigger the response. We predict that we will find

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the same growth response, indicating that *A. percula* is responding to the territory size provided by the anemone, which predicts foraging area in the wild. Finally, we took the predicted values from a mixed model fitted to the lab data, including initial size of fish and anemone size as predictors, and compared them to size data in a wild population of A. percula associated with *Heteractis magnifica*. We found high overlap in predicted and actual sizes. Together, we provide the first example of vertebrate growth plasticity in response to a mutualistic interaction, as well as possible fitness consequences.

31-1 Ruhl, NA*; Ruggiero, DA; Iuliucci, SC; Rollo, FA; Grove, MW; Richmond, CE; Rowan University; *ruhl@rowan.edu*

Water quality determinants of the density of zooplankton subsidies from polymictic reservoirs to streams

Damming of streams inserts a lentic system (a reservoir) into a lotic system (the stream) thereby changing downstream hydrological, biogeochemical, and ecological attributes of streams. One way in which reservoirs alter ecological interactions is through the conversion of both primary and secondary productivity from benthic to planktonic organisms. Planktonic subsidies cause a shift in downstream community composition toward filter feeders. Filter feeders obtain resources as a function of the density of those resources in the environment. Measuring zooplankton density is a labor intensive process, so in this study we assess whether the density of zooplankton subsidies can be predicted by water quality variables, which would be a much more efficient way of quantifying zooplankton subsidy. During the 2019 growing season we monitored zooplankton subsidy from four polymictic reservoirs and assessed 22 water quality variables for their ability to predict subsidies. Phosphate concentration and conductivity were the best combined predictors in 2019. These variables were used in a 2018 pilot study following similar methodology. When both years were considered conductivity emerged as the best predictor of zooplankton density, ultimately predicting about a third of the variation in zooplankton density. We detected shifts in water quality conditions during 2019, but these shifts in water quality did not affect the density of zooplankton subsidies. Conductivity can be used as a screening

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tool to identify small polymictic reservoirs with higher densities of zooplankton subsidy.

103-8 Rull, M*; Bouvier, C; Konow, N; UMass Lowell; *Mateo_Rull@student.uml.edu*

Tongue kinematics change across terrestrialization in ambystomatid salamanders

Amphibian metamorphosis often involves terrestrialization with associated changes that exemplify adaptations necessary for land invasion, which Devonian proto-tetrapods must have negotiated. Underwater, fish often utilize suction feeding, exploiting water's hydrodynamic properties to transport food within the mouth. By contrast, air-based feeding requires direct tongue-based food manipulation. In both water and air, the tongue is an important component of the feeding apparatus, but our understanding of mechanical adaptations of tongues across terrestrialization is poor. Using ambystomatid salamanders, we investigate tongue movement with respect to the jaw and the food during feeding. Subjects and their food items are implanted with radiopaque markers that are tracked via video-fluoroscopy. We hypothesize that there is a decoupling of food and tongue motion as aquatic tongues retract and depress during gape opening. By contrast, in air, we hypothesize that tongues elevate and protract as the mouth opens in synchrony with food motion, as seen in lepidosaurs and mammals. We use tongue, food, and jaw motion loops to show that, during aquatic food processing, onset of food motion lags approximately 18% from onset of tongue motion, with a near-zero lag in air. Further, using a 3D skull reference coordinate system, we show that aquatic tongues retract and depress as the mouth opens, while terrestrial tongues translate in the opposite direction along each plane. Thus, the timing and nature of tongue-based food control changes profoundly as ambystomatids terrestrialize, supporting our hypotheses of an ancestral hydrodynamic-tongue system for aquatic feeding being substantially altered across terrestrialization. Our results illustrate some overlooked challenges that proto-tetrapods negotiated as they invaded land.

107-7 Rummel, AD*; Swartz, SM; Marsh, RL; Brown

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University; *andrea_rummel@brown.edu*

Physiological adaptation to local temperature differences among bat wing muscles

The high, constant body temperatures (T_b) of endotherms like birds and mammals are thought to facilitate the specialization of biochemical processes to warm temperatures, but endotherms experience temperature variation in body regions that can be extreme, even as they tightly regulate core T_b. Bats have poorly thermally insulated wing muscles, separated from the environment by only a thin layer of skin and little to no fat or fur, making them vulnerable to heat loss. We hypothesized that (1) peripheral muscles further from the core would operate at lower temperatures than core muscles; (2) to compensate for lower operating temperatures, these peripheral muscles would be less temperature sensitive than core muscles; and (3) differences in the temperature sensitivity of muscle contractile properties would be due to differing properties of the enzymes that mediate muscle contraction. We addressed these hypotheses in *Carollia perspicillata*, a Neotropical fruit bat, by measuring wing muscle temperatures continuously during wind tunnel flights; shortening velocity and relaxation rates across temperatures in strips of the pectoralis and whole muscle preparations of a forearm and hand muscle from the same species; and myosin enzyme activities from the pectoralis and forearm muscles across temperatures. In vivo pectoralis temperatures matched T_b closely, but forearm muscle temperatures were 12°C below T_b on average. Contractile rates in the peripheral muscles were significantly less temperature sensitive than those of pectoralis, suggesting that they are able to better maintain function at their low operating temperatures, which is likely due to a significant difference in thermal stability of myofibrillar ATPase between the pectoralis and forearm muscles.

95-11 Rump, MT*; Kozma, MT; Derby, CD; Georgia State University, Colorado State University; *mrump1@student.gsu.edu*

G-protein coupled receptors in chemosensory organs of decapod crustaceans

Decapod crustaceans rely on multiple chemosensory organs such as the walking leg dactyls and lateral flagella (LF) of the antennules

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for chemical sensing. Chemosensory neurons in these organs rely on certain classes of receptor proteins to act as external sensors and to regulate signal transduction. G-protein coupled receptors (GPCR) regulate neuronal activity in most animals and mediate chemical sensing in many animals (primarily vertebrates). GPCRs are pervasive throughout the animal kingdom, and the class A (rhodopsin-like) sub-family is the most diverse group. Class A GPCRs regulate neurotransmission and neuromodulation, and serve as receptors for external stimuli of many modalities. To identify gene expression of GPCRs in chemosensory organs of decapod crustaceans, we analyzed transcriptomes from LF and dactyl from four decapods: *Panulirus argus*, *Homarus americanus*, *Procambarus clarkii*, and *Callinectes sapidus*. We also analyzed single cell transcriptomes (SCT) from olfactory sensory neurons (OSNs) of *P. argus*. Putative GPCRs were identified through InterProScan and phylogenetically classified based on sequence similarity. In total, 399 putative class A GPCR sequences were detected with 99 from *P. argus*, 94 from *H. americanus*, 125 from *P. clarkii*, and 81 from *C. sapidus*. Homologues were separated into six sub-classes comprising 13 opsins, 28 small molecule receptors, 49 neuropeptide receptors, 7 leucine-rich repeat-containing GPCRs, 18 deuterostome-like GPCRs, and 31 orphan GPCRs. Collectively, 63 sequences were enriched in the chemosensory organs, 45 had higher expression in the LF than the dactyl, and 54 sequences were expressed in OSNs of *P. argus*. We identified potential modulatory GPCRs such as a metabotropic histamine receptor, and several orphan receptors and opsins that may serve as environmental sensors.

35-6 Ruopp, R*; Wang, L; Lee, S; Full, R; University of California, Berkeley; *rruopp@berkeley.edu*

Cognitive biomechanical decisions to negotiate unstable branches in fox squirrels

Cognitive Biomechanical Decisions to Negotiate Unstable Branches in Fox Squirrels. *RUOPP, R.*; WANG, L; LEE. S.; FULL, R.J. Univ. of California, Berkeley.* rruopp@berkeley.edu Arboreal agility requires more than skilled biomechanics. Critical cognitive behavioral decisions often must be made instantly including knowledge of biomechanical capability. We challenged free-ranging Fox squirrels to jump across three elevated branch-like rods in the same plane,

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but perpendicular to their forward path in return for a food reward. We varied the spacing of the rods (25, 37, 50, and 62cm) and the stability of the center rod from fixed (Non-Rotating, NR) to rotating (R). We recorded behavioral decisions and leaping kinematics with four high-speed video cameras for 652 leaping trials from twelve, identifiable individuals. Using a Markov-like chain analysis, we found that as jump distance increased failures to negotiate the R rod increased. Squirrels showed exploratory testing behavior by jumping to the center R rod and then back to the starting NR rod. Variation of the strategies selected increased most after a failure. Remarkably, as gap distance increased (50 cm) and stable landing on the R rod became more challenging, squirrels showed innovation by unexpectedly leaping high onto the fixed side structures securing the rods, bypassing the R rod. Eventually squirrels learned to leap stably from the R rod to cross the entire set-up, especially at the greatest gap distances where other biomechanical options appeared more limited. With further analysis and by inclusion of additional obstacles and controls, we hope to develop a model of embodied learning and control that will serve as biological inspiration for the most agile robot yet built.

S3-5 Russell, AL; Missouri State University; *AveryRussell@MissouriState.edu*

Ecological and evolutionary consequences of flexible foraging behavior for bees and flowers

Flexibility in behavior is thought to enable evolutionary success and can shape the ecology and possibly the evolution of mutualist partners. Bees foraging on flowers constitute a model mutualism for studying the consequences of behavioral flexibility. We show that flexibility in pollen extraction behavior by bees involves switching between two behaviors: scrabbling (involving vigorous leg movements) and buzzing (involving powerful thoracic vibrations). This behavioral flexibility benefits the bee, increasing their rate of pollen collection. Surprisingly, this behavioral flexibility simultaneously reduces bees' effectiveness as pollinators, with buzzing bees transferring less pollen than scrabbling bees. Over evolutionary timescales, we also find that behavioral flexibility in pollen extraction behavior evolved early and repeatedly (~45 independent origins) in bees and may be a key driver of

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evolutionary diversification in bees. This behavioral flexibility has likely also driven the extraordinarily repeated evolution (>200 independent origins) of pollen concealment via tube-like anthers or corollas (i.e., poricidal floral morphology), which occur in >635 genera of flowering plant species (27,000 species, or 10% of all angiosperm species). However, we also find that poricidal plant species diversify more slowly and more frequently transition away from poricidal morphology, potentially a result of ecological consequences mentioned above. Altogether, our results suggest that the ecological effects of flexibility in behavior can have far reaching consequences for the evolution of mutualist partners.

S10-10 Ruszczyk, M*; Webster, DR; Yen, J; Georgia Institute of Technology; *mruszczyk3@gatech.edu*

Dual phase-shifted ipsilateral metachrony in Americamysis bahia

Previously-documented metachrony in euphausiids has focused on one metachronal stroke, where pleopods on the same abdominal segment beat in tandem with each other propelling the animal forward. In contrast, the mysid shrimp *Americamysis bahia*'s pleopods on the same abdominal segment beat independently of each other, resulting in dual phase-shifted ipsilateral, metachronal strokes along the length of the body. The parameters of these independent strokes and their synchrony is investigated in free-swimming *A. bahia*. Concurrent strokes have the same beat frequency and similar phase lag profiles between adjacent ipsilateral appendages, though the strokes are 176.5±11.5° (n = 13 cycles, mean±standard error) out of phase. In comparison to the euphausiids *Euphausia pacifica* and *E. superba*, who achieve three distinct swimming modes by altering their beat frequency and phase lag, *A. bahia* only achieves fast forward swimming using its pleopods. Instead, the mysid primarily relies on its thoracic appendages for swimming, suggesting that there are limitations to what dual phase-shifted ipsilateral metachrony at can achieve at this length scale.

59-4 Ruthsatz, K*; Dausmann, KH; Peck, MA; Glos, J; Technical University of Braunschweig, University of Hamburg, Royal Netherlands Institute for Sea Research; *katharinaruthsatz@gmail.com*

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Potential of thermal tolerance plasticity as a coping mechanism with global warming in amphibians

The capacity for phenotypic plasticity offers a potential to buffer ectotherms with complex life histories such as amphibians from impacts of climate change. In particular, plasticity in thermal tolerance (i.e. acclimation) has been proposed as a proxy for determine a species' vulnerability to global warming. However, thermal tolerance varies between life stages and so acclimation capacity will. We assessed the potential of plasticity in thermal tolerance as a coping mechanism with global warming in the common frog (*Rana temporaria*) during ontogeny. We investigated how acclimation temperature influences lower (CTmin) and upper (CTmax) thermal limits and how acclimation capacity of *R. temporaria* changes throughout ontogeny by calculating a stage-specific plasticity index. Also, we compared the acclimation capacity of *R. temporaria* and other species in a combined analysis. CTmax was more sensitive to temperature variation than CTmin and thus, more plastic. CTmin was most plastic in animals directly after hatching, followed by animals at the onset, during and after metamorphic climax. CTmax was least plastic in animals directly after hatching and most plastic in animals before the onset of metamorphic climax and in juvenile froglets. We found that *R. temporaria* has a low acclimation capacity at early stages which increases with proceeding ontogeny. Therefore, plasticity in thermal tolerance might help *R. temporaria* successful mitigating effects of global warming in later larval and juvenile stages but not directly after hatching. Further, our results indicate that *R. temporaria* has a relatively high acclimation capacity in CTmax compared to other amphibian species.

19-9 Rutter, AR*; Roberts, TJ; Brown University; *amy_rutter@brown.edu*

Amplitude patterns in woodpecker drumming

Auditory communication is utilized by many avian species for territorial defense and sexual selection. A primary mode of communication for woodpeckers (Aves: Picidae) is drumming in which an atonal acoustic signal is generated by rapidly beating the bill against a resonant substrate (e.g., tree). Similar to bird song, woodpecker drums exhibit characteristic patterns, including

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frequency (beats/s), length, and rhythm. Given the patterns evident in these features, we wanted to determine whether a consistent pattern of amplitude could be observed in woodpecker drums. To investigate this, we analyzed audio of Downy Woodpeckers (*Dryobates pubescens*) drumming from both our own sound recordings and those publicly available from the Macaulay Library at the Cornell Lab of Ornithology and Xeno-canto. We measured sound amplitude from the waveform of each recording as the peak amplitude of each beat within a single drum. Beat amplitudes were then normalized to account for the variation in amplitude scaling between recordings. We found that most drums begin with a "ramp-up," where the amplitude increases within the first few beats of a drum. The other characteristic patterns of the drumming signal—frequency, length, and rhythm—vary from one species to another and may be integral to species recognition. The observed ramp-up pattern in amplitude may be encoding communication information, but we speculate that it may also reveal evidence of elastic contributions to this physically challenging behavior. We intend to broaden our dataset to include additional woodpecker species to see if this pattern holds.

43-6 Ryan, TA*; Taff, CC; Zimmer, C; Vitousek, MN; Cornell University; *tar87@cornell.edu*

Temperature-induced priming of the glucose response to subsequent challenges

Capricious environments often present wild animals with challenges that coincide or occur in sequence. Conceptual models of the stress response predict that one threat may prime or dampen the response to another. Although this has been widely shown for glucocorticoid responses, much less is known about the effects of previous challenges on energy mobilization. Food limitation may have particularly important priming effects, by altering the ability to mobilize energy when faced with a subsequent challenge. We tested the prediction that challenging weather conditions, which reduce food availability, alter the energetic response to a subsequent acute challenge (capture and restraint). Using a three-year dataset from female tree swallows measured during three substages of breeding, we asked if weather (temperature, wind speed, and precipitation) over 3- or 72-hour timescales predicted baseline and post-restraint glucose levels. Contrary to our predictions, weather

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conditions did not affect baseline glucose. However, as predicted, birds that had experienced lower temperatures over the preceding 72 hours mounted higher glucose stress responses. We also saw some support for an effect of rainfall on stress-induced glucose: around the time of hatching, birds that experienced more rainfall over the preceding 72 hours mounted lower responses. Overall, we find support in a wild animal for the idea that the glucose stress response may be primed or dampened by exposure to prior challenges.

3-2 Ryerson, WG*; Van Valkenburg, T; Saint Anselm College; *wryerson@anselm.edu*

Integrating tooth shape with strike mechanics in the process of prey capture in Boa constrictor

Snakes, with the obvious exception of the fangs, are considered to lack the regional specialization of tooth shape and function that are exemplified by mammals. Recent work in fishes has suggested the definition of homodont and heterodont are incomplete without a full understanding of both the morphology, mechanics, and behavior of feeding. To further test this hypothesis, we investigate changes in tooth shape along the jaw of *Boa constrictor* and correlated these changes with the strike kinematics of boas feeding on rodent prey. We divided the upper and lower jaws into thirds, and calculated the curvature and of each tooth of the jaws as well as those found on the palatine and pterygoid bones. For strike kinematics, we filmed six adult boas striking at previously killed rats. We determined the regions of the jaws that made first contact with the prey, and extrapolated the relative positions of those teeth at that moment. We further determined the roles of all the teeth throughout the prey capture process, from the initiation of the strike until constriction began. We found that teeth in the anterior third of the lower jaw are the most upright, and that teeth become progressively more curved posteriorly. Teeth in the upper jaw are more curved than the lower jaw, with the exception of the most posterior lower jaw, and there are no regional differences among teeth in the upper jaw. A close examination of the strike kinematics revealed that the anterior portion of the lower jaw was the most frequent point of first contact. The momentum from the strike caused the upper jaws to rotate over the rat. The more curved teeth of the upper jaw slid over the rat unimpeded until the

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snake began to close its jaws. The curved teeth of the palatine and pterygoid bones assist in the process of the swallowing.

17-4 Sadowska, J*; Medlock, S; Carlson, KM; Buck, CL; Duddleston, KN; Department of Evolutionary and Physiological Ecology, Faculty of Biology, University of Białystok, Poland, Department of Biological Sciences, College of Arts and Sciences, University of Alaska Anchorage, USA, Department of Biological Sciences, Northern Arizona University, Flagstaff, USA; *julita.sadowska@uwb.edu.pl*
Significance of microbially-liberated urea-nitrogen in pregnant and lactating arctic ground squirrels
Gut microbes may influence host energy balance via a process called Urea Nitrogen Salvage (UNS). This microbial recycling has been proposed as a mechanism for nitrogen conservation in hibernators. The arctic ground squirrel is an exceptional hibernator, displaying the most extreme hibernation phenotype known: hibernation lasts up to nine months with no food or water consumption, and Tb during torpor is regulated at -2.9° C, the lowest of any mammal. That leaves the animal with just a short window of activity to complete the full reproductive cycle and prepare for the next hibernation. Earlier studies suggest that demands of hibernation might have enabled selection of the ureolytic microflora and increased relevance of UNS as a source of N. Here we tested whether high protein demands of gestation and lactation also increase incorporation of microbially-liberated urea-N into maternal tissues of active squirrels. Gestating and lactating animals were fed either a protein deficient or protein sufficient diet throughout the entire reproductive cycle. We measured microbial urea-N incorporation using isotopically labeled urea and assessed the bacterial diversity of gut microbiota. We found higher ureolytic bacteria activity and urea-N incorporation in the protein deficient group. Lactating squirrels on the protein deficient diet showed the highest incorporation of urea-N in their tissue and breath, signifying higher UNS.

63-7 Saenz, V*; Rollins-Smith, L; Hall, EM; Reinert, L; Ohmer, ME; Richards-Zawacki, C; University of Pittsburgh, Vanderbilt University; *ves24@pitt.edu*

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Effects of simulated climate warming on the development of immune defenses in juvenile leopard frogs

Climate change will have negative impacts on diverse taxonomic groups, and ectotherms are particularly at risk because their physiology is so closely tied to the environment. For ectotherms, changes in temperature affect metabolism, development, growth, movement, reproduction, and immunity. To better understand the potential for climate change to impact amphibian immune defenses, I compared (a) the development of immune defenses and (b) the impact of exposure to the chytrid fungus Batrachochytrium dendrobatidis (Bd) among juvenile leopard frogs from three latitudes that had developed under simulated current and future climate conditions. Few studies have examined the impact of increased environmental temperatures during larval development on immune defenses that are expressed after metamorphosis. We predicted that exposure to stressful temperatures early in life would result in juvenile frogs with compromised immune defenses. As predicted, frogs raised as larvae under simulated climate change scenarios metamorphosed faster, and at a reduced body size and mass, compared to frogs raised under their simulated current climates. Effects of simulated warming on immune parameters and disease development differed among latitudes/populations of origin: frogs from our middle latitude were less likely to become infected with Bd as juvenile frogs if they had developed as larvae under simulated future climate scenarios, and frogs from our highest and lowest latitudes that developed as larvae under simulated warming had underdeveloped antimicrobial peptides. In some populations we also found differences in immune cell (white blood cells and/or thymocytes) counts in juvenile frogs that developed as larvae under different climate scenarios.

73-1 Saintsing, AJ*; Full, RJ; University of California, Berkeley; *andrew_saintsing@berkeley.edu*

Effects of leg loss depend on the leg lost in cockroaches

Cockroaches are robust to leg loss, but performance may depend on the leg lost. Previously, we discovered that middle leg loss is energetically costly for cockroaches, *Blaberus discoidalis*, likely because instability forces them to take shorter, faster steps. It is unclear that removal of the front or hind legs would have the

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same impact. We hypothesized that the loss of hind legs would be energetically costly to cockroaches because greater force might be required to stabilize or drag the unsupported abdomen. We ran cockroaches on a treadmill until they could no longer match the set speed ranging from 30-220 cm/s. Simultaneously, we measured steady-state oxygen consumption, stride frequency, and ground contact time. We collected each measurement for intact individuals, then collected the same measurements after the individual had a single hind leg ablated and then both hind legs removed. We found no significant changes in the rate of oxygen consumption, ground contact time, or stride frequency of individuals after leg loss. Hind leg loss did not significantly lower endurance. However, cockroaches with hind leg loss did adopt a different running strategy compared to intact cockroaches. Cockroaches missing hind legs used an intermittent locomotion strategy with more trials showing brief pauses where they rested their unsupported abdomens. The inability to continuously generate propulsive forces suggests that, while hind leg loss may not increase metabolic cost, it's consequences likely limit the ability for continuous locomotion. Energetic expenditure cannot fully capture the cost of leg loss.

66-8 Salcedo, MK*; Shevchenko, PD; Socha, JJ; Virginia Tech, Blacksburg, VA, Argonne National Laboratory, Lemont, IL; *msalcedo@vt.edu*

Whole-wing microtomographic imaging of grasshopper wings

Wings allow an insect to perform ecologically important behaviors including predation, migration, and pollination, and also serve as inspiration for insect-size micro-air vehicles. Recent evidence confirms the importance of wing flexibility in aerodynamic force production, suggesting that hydration, via hemolymph, is essential to maintaining the aerodynamic function of wings, as well as maintaining local sensory structures. Hemolymph circulates through insect wing veins; however, how flow is delivered to the wings is not well understood. Here, we report a complete three-dimensional morphology of the network of veins in the wings of grasshoppers, providing the basis for new models to study patterns of hemolymph movement. High-resolution tomography of wings was conducted using synchrotron x-ray imaging at the Advanced Photon Source, Argonne National Laboratory. Scans were performed on whole wings of

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recently sacrificed insects, examining venation of the adult forewing and hindwing of four North American grasshoppers, *Schistocerca Americana*, and unexpanded wings of six migratory grasshoppers, *Melanoplus sanguinipes*, totaling 30 wing scans. Fast scanning (<2 min/section) helped to ensure that tracheal tubes remained intact in freshly sacrificed insects. Preliminary analyses suggest that within a wing vein, the relative proportion of hemolymph space, tracheal volume, and vein wall thickness shifts dramatically over the span of the wing. These data provide accurate 3D models of insect wings, informing further studies on hemolymph circulation in the wings. Supported by NSF 1812215 and 1558052.

99-6 Saleh, NW*; Henske, J; Ramirez, S; University of California, Davis, Ruhr University Bochum; *nsaleh@ucdavis.edu*

Assessing behavioral and reproductive plasticity in a social orchid bee

Social insects display remarkable plasticity, with a wide range of behavioral and physiological phenotypes induced by environmental factors throughout development and adulthood. This is most dramatically seen in the extreme physiological differences between queens and non-reproductive workers in eusocial insects such as honey bees, where caste differences are induced by diet. In species with small, casteless social groups less is known about the degree to which individuals can express similar changes in reproductive physiology. Some orchid bees, until recently thought of as solitary, have been shown to form small social groups of a single dominant bee and 1-2 subordinate helpers. However, little is known about degree of reproductive and behavioral specialization in these social groups. Here, we assess individual plasticity of social subordinates of the orchid bee *Euglossa dilemma*. We first performed an experiment to disrupt social nesting and then followed the behavioral, physiological, chemical, and transcriptomic responses of socially isolated subordinates in the field. We found that isolated subordinates express dramatic behavioral and physiological changes not typically seen in subordinate bees, demonstrating a high level of individual plasticity. Further, genes involved in these changes overlap substantially with genes involved in worker

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physiology in eusocial species, suggesting conserved mechanisms of plasticity in bees.

BSP-2-6 Salem, W*; Mongeau, JM; The Pennsylvania State University; *was29@psu.edu*

Flying in an uncertain world: system identification of flight performance following wing damage in fruit flies

Insects are some of the most adaptable fliers in nature as they readily adapt to changes in the environment and physical damage. The robustness of flying insects to wing damage is of particular interest since insects cannot repair wings. Thus, flying insects must rely on neuromechanical control strategies to compensate for wing damage. While insects can retain the ability to fly after wing damage, its effect on flight performance remains poorly understood. We conducted a frequency domain analysis of magnetically tethered fruit flies with intact and asymmetrically damaged wings (missing 10-40% of the wing area). In response to oscillating stimuli, the optomotor response of intact-wing flies was tuned to frequencies between 0.4-3 Hz. The optomotor response of both groups was strongest for frequencies between 0.2 and 1.5 Hz and was mostly attenuated at frequencies above 2.4 Hz. The phase lag decreased gradually with increasing frequency, suggesting a constant delay. A statistical comparison of the performance of both groups yielded a frequency-dependent influence of wing damage on flight response gain but not on phase. In addition, damaged-wing flies drifted in the direction of the damaged wing. During gaze stabilization, flies compensated for wing damage by decreasing the amplitude of the intact wing, whereas the amplitude of the damaged wing remained unchanged compared to the intact-wing group. Frequency domain analysis revealed that by using neuromechanical control strategies, fruit flies compensated partially for asymmetric damage but achieved diminished flight performance. A system identification framework can reveal performance tradeoffs and provide insights into how animals compensate for perturbations in an uncertain world.

21-7 Samuels, B*; MacDougall-Shackleton, S; Fenton, B; The University of Western Ontario, Department of Biology, London, ON,

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Opening the black box of bird-window collisions: passive field recording and experiments in laboratory

Collisions with windows on buildings are a leading direct source of anthropogenic mortality for birds. A common scenario in which birds impact windows is at single-family residences with nearby bird attractants, such as bird feeders and bathing stations. Scientific understanding of bird collisions is limited by a lack of empirical data on how collisions actually happen. Previous studies have documented evidence of collisions after-the-fact (i.e. bird carcasses) but none have observed collision events directly. As a result, many assumptions about bird collisions and methods for prevention have yet to be tested. We developed two methods for documenting, measuring and comparing bird-window collisions in the field and in a laboratory setting. First, we positioned a home security camera system in a residential backyard near bird feeders and passively recorded a variety of wild bird species interacting with windows on the home over two years. From the footage, we estimated birds' flight speed, angle of approaching the window, and any observable outcome of collision events. Second, we created an indoor flight arena to simulate collisions with windows by having house sparrows (Passer domesticus) impact and bounce off a lightweight transparent plastic sheet. During flight trials, we recorded changes in birds' flight speed, trajectory and head angle upon approach using high-speed cameras in order to characterize the spatial parameters of birds detecting and avoiding an obstacle. We will discuss findings of analyses of collision footage from the field and captive experiments, and implications for interpreting the causes and effects of collisions with windows at the level of individual birds.

97-1 Sánchez-Martínez, PM; Daza, JD*; Hoyos, JM; Pontificia Universidad Javeriana, Departamento de Biología, Bogotá, Colombia , Sam Houston State University, Huntsville, TX; *juand.daza@gmail.com*

Evolution of the lizard middle ear

The middle ear in squamate reptiles is formed by three elements, columella, extracolumella, and tympanic membrane. The main function of this segment of the ear is to transform sound pressures into

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vibrations, and to transmit these vibrations into the inner ear. In lizards, the morphology of the columella is highly conservative, while the extracolumella shows a wide variation in size, shape, and the amount of processes derived from it. Here we surveyed 24 lizard genera using clear and stained specimens to study the morphology of the middle ear. The data collected was combined with data from previous descriptions, and these characters were used for ancestral character inference using parsimony and Bayesian approaches. One of the characters studied show high levels of homoplasy, while two of them would serve to diagnose some clades. Geckos showed complex morphologies in the shape of the extracolumella, including an expansion of this structure. It is possible that the observed traits in geckos make them more sensitive to sounds, which is congruent with their ability to produce complex vocalizations, which are more similar to mammals and birds than other lizards. Finally, fossorial forms and snakes showed a tendency to lost the extracolumella, which also is an specialization to perceive ground-borne vibrations.

41-8 Sanders, BC*; Ruhl, N; Rowan University; *bailey.sanders@mnsu.edu*

Exploring the nature and process of science with abnormal frogs

The frog abnormalities phenomenon was first discovered by students on a field trip in 1995 and their discovery sparked hundreds of scientific studies. This discovery has been integrated into the curriculum of thousands of students as a way to learn the scientific method, but the frog abnormality phenomenon is also well suited as a socio-scientific issue for teaching students about both the nature and process of science. Our goal here is to provide an integrative resource for post-secondary biology and environmental educators to incorporate frog abnormalities into their course context. We review the frog abnormality phenomenon, discuss frog abnormalities in the context of a socio-scientific issue, suggest ways in which post-secondary educators can teach the nature and process of science using frog abnormalities, and offer ideas for non-science educators to connect to the sciences using frog abnormalities.

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21-8 Sandoval Herrera, NI*; Faure, PA; Welch Jr., K; Biological Sciences, University of Toronto, Scarborough,Canada, Department of Psychology, Neuroscience & Behaviour, McMaster University, Hamilton, Canada; *natalia.sandovalherrera@mail.utoronto.ca*

Is spatial navigation in echolocating bats affected by pesticides?

Bats are potentially exposed to pesticides by eating contaminated insects in croplands. Commonly used pesticides such as organophosphates (OPs) are neurotoxic for non-target vertebrate species and even low doses can impair essential processes such as locomotion and cognition. These neurotoxic effects are usually sublethal and can therefore be difficult to study using traditional toxicological assessments. Behavioral studies are a promising alternative to evaluate sublethal effects on bats. Echolocating bats usually develop individual stereotyped flight patterns as they become familiar with a novel space. We evaluated bats' ability to memorize and navigate a new space by comparing the consistency of these repetitive trajectories between exposed and unexposed bats. We orally dosed captive big brown bats (Eptesicus fuscus) with an environmentally relevant concentration of Chlorpyrifos, a commonly used insecticide. We tracked their flight behavior while exploring a flight tent. We evaluated the similarity in their trajectories within and among trials, time spent in flight, and landing frequency. We also quantified the ChE activity in brain and plasma as a biomarker of the potential mechanism of neurotoxicity. Preliminary results suggest an increase in the variability of the trajectory in exposed bats within trials, and an increase in landing frequency compared to unexposed bats. Exposed bats presented a 60% reduction of the brain ChE activity. These results support the sensitivity of behavior as a biomarker of toxicity and as a tool to elucidate potential ecological implications of anthropogenic stressors on wildlife.

110-10 Santana, SE*; Kaliszewska, ZA; Leiser-Miller, LB; Lauterbur, ME; Arbour, JH; Davalos, LM; Riffell, JA; University of Washington, University of Arizona, Middle Tennessee State University, State University of New York at Stony Brook; *ssantana@uw.edu*

Evolution of fruit scent in neotropical pepper plants: a test of the dispersal syndrome hypothesis

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The dispersal syndrome hypothesis poses that animal-mediated seed dispersal led to the evolution of fruit traits that match the physical, sensory and behavioral attributes of mutualistic frugivores. Previous work has provided mixed support for this hypothesis and few studies have addressed complex traits such as fruit scent, even though these chemical signals are a primarily means through which many mammalian frugivores identify ripe fruit. Here, we investigate whether volatile compounds emitted by the fruits of neotropical pepper plants (*Piper* spp.) evolved in response to seed dispersal by scent-oriented bats (*Carollia* spp.). To test this hypothesis, we conducted phylogenetic comparative analyses that relate the diet of three *Carollia* species, experimentally-derived bat scent preferences, and fruit scent chemical composition across 22 *Piper* species in a locality in Costa Rica. We demonstrate that fruit scent chemical composition lacks a phylogenetic signal; instead, chemical diversity and presence of specific compounds fit adaptive evolutionary scenarios that are consistent with increased bat consumption and chemical preferences. Specifically, *Carollia* prefer certain compounds, particularly 2-heptanol, which evolved as a unique feature of *Piper* species highly consumed by these bats. While other abiotic and biotic processes likely helped shape the chemical diversity of *Piper* ripe fruit scent, the evolutionary patterns of some chemical components are consistent with a bat dispersal syndrome.

S10-8 Santhanakrishnan, A*; Ford, MP; Oklahoma State University; *askrish@okstate.edu*

Hydrodynamics of metachronal paddling

As an aquatic locomotion strategy, metachronal paddling is used by organisms across a wide number of distantly related taxa. The broad diversity of body and appendage morphologies of metachronal swimmers make it difficult to generalize how specific morphological and kinematic parameters impact swimming performance. Biorobotics approaches can be particularly useful in this context to synthesize physical design principles underlying this successful locomotion strategy. We summarize our studies using tethered and self-propelling dynamically scaled robotic models of metachronal paddling to address the following questions: (1) How do negatively buoyant crustaceans generate downward momentum to support their

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weight while hovering? (2) How does varying the distance between neighboring appendages affect swimming performance? (3) How does varying stroke kinematics (inter-appendage phase lag) affect swimming performance? We use quantitative flow visualization measurements to identify physical mechanisms that explain the observed changes in swimming speed. We find that hydrodynamic interaction of the wakes of closely spaced paddles can increase forward swimming speed. Paddling with a non-zero phase lag promotes the formation of counter-rotating vortices, and their interaction results in generation of large-scale angled downward jets that can provide vertical momentum necessary to support body weight during hovering. The use of a metachronal power stroke followed by a synchronous recovery stroke allows for large stroke amplitudes even with close appendage spacing, resulting in an appreciable increase in swimming speed. This pattern of hybrid stroke kinematics is seen in escaping copepods and mantis shrimp, and serves as an example of how the metachronal propulsion system can be adapted for a range of behavioral and ecological needs.

77-9 Santibanez-Lopez, CE*; Ballesteros, JA; Baker, CM; Gavish-Regev, E; Sharma, PP; Department of Biology, Eastern Connecticut State University, 83 Windham Street, Willimantic, CT 06226, Department of Integrative Biology, University of Wisconsin-Madison, Madison, WI 53706, National Natural History Collections, The Hebrew University of Jerusalem, Jerusalem, Israel; *santibanezlopezc@easternct.edu*

Co-diversification of scorpion mammalian predators and mammal-specific sodium channel toxins in scorpion venom

Scorpions constitute an ancient lineage of arachnids with more than 2,500 described species distributed worldwide. While all scorpions are venomous, nearly 60 species are medically significant to humans, with all but one included in the family Buthidae. In recent years, the study of scorpion venom components has benefited from next-generation sequencing and high throughput proteomic analyses, but the evolutionary history of the most toxic scorpion genera remains unclear. Here, we assembled a large-scale phylogenomic dataset of 100 scorpion venom transcriptomes and/or genomes, including exemplars of highly toxic buthid genera. We inferred divergence times of venom gene families, including those affecting

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mammal-specific tissues, using a phylogenomic node dating approach and phylostratigraphic bracketing for inferring gene ages. Our results showed that mammal-specific sodium channel toxins have independently evolved in five lineages within Buthidae, with these gains temporally coincident with the diversification of major scorpion mammal predators.

3-3 Sargent, AJ*; Rico-Guevara, A; Groom, DJE; University of Washington; *sargena@uw.edu*

Reassessing hummingbird foraging: Is there a territoriality-traplining continuum?

Hummingbirds' main foraging strategies are often presented dichotomously: territorialism (defending a small patch of flowers) or traplining (foraging over routine circuits of isolated patches). As such, traplining hummingbirds are largely considered nonterritorial. However, this dichotomy has been inconsistently defined within the behavioral literature; indeed, recent studies have challenged this binary approach entirely, and territorialism and traplining may comprise a continuum of strategies rather than mutually exclusive options. In the past, each behavior has been associated with distinct avenues of selection: trapliners maximizing foraging efficiency, and territorialists favoring speed and maneuverability for resource defense. These functions were primarily examined through wing disc loading (ratio of body weight to the circular area swept out by the wings, WDL) and predictive hovering costs, with trapliners characterized by low WDL and thus lower hovering costs. More recent studies, however, have dismantled these models when applied to hummingbird assemblages. Current technological advances have allowed for innovative, applied research on the biomechanics/energetics of hummingbird flight, such as allometric scaling relationships (e.g., wing area-flight performance) and the link between high burst lifting performance and territoriality. This work suggests there are biomechanical trade-offs to different strategies, yielding a foraging spectrum of divergent optima, towards either end of which birds have specialized. By interpreting foraging in the context of these optima, and combining these analyses with a field-validated behavioral lens, we may be able to clarify territorialism and

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traplining definitions, and explicitly characterize traplining behaviors of territorial individuals.

56-4 Sathe, EA*; Dudley, R; University of California, Berkeley; *eksathe@berkeley.edu*

Evolutionary diversification of aerial control in the genus Anolis

Anole lizards (genus *Anolis*) have repeatedly and independently filled arboreal niches, and in parallel have evolved specific morphologies and features of locomotor performance. Controlled falls and gliding have typically evolved in concert with arboreality given an increased selective pressure to target and control landings during falls or intentional jumps from height. Directed aerial descent, in particular, is a locomotor mode often associated with an arboreal habitat, elongate appendages, and high surface area relative to body mass. Here, we assess morphological features among anole species that correlate with aerial performance, and hypothesize that greater body mass would correlate with greater glide angles. We used a vertical wind tunnel to simulate gliding by three to five individuals of each of five anole species representing various ecomorphs. For each lizard, we analyzed five glide trials as filmed at 400 fps. To extract three-dimensional positional data, we tracked four landmarks along the lizard's spine using MATLAB. We smoothed these data with a quintic spline and estimated the velocity and acceleration with the first and second derivatives, respectively; flight performance was quantified from additional kinematic features including pitch, heading, body velocity, and glide ratio. We used comparative methods to account for phylogenetic relationships among the species, and found that aerial behavior and gliding performance differed substantially among anole ecomorphs.

27-6 Sayavong, N*; Estrada, M; Salas, H; Gunderson, AR; Stillman, JH; Tsukimura, B; California State University, Fresno; *sayavongnathan@gmail.com*

The transduction of climate change in rocky intertidal porcelain crabs P. cinctipes and P. manimaculus through thermal stress, increased density, and competition

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Global change is known to affect species distribution. Understanding the resulting physiological responses of organisms is critical for predicting community composition changes that may occur under current and future conditions. The porcelain crab, *Petrolisthes cinctipes*, resides in the upper to mid intertidal zone and is expected to respond to rising temperatures by shifting its distribution lower in the cooler intertidal zone, where they will experience higher densities. They will also interact more often with its congener, *Petrolisthes manimaculus*. In this study, I addressed how increased density, species interactions (inter- and intra-), and increased temperature impact reproduction on *P. manimaculus* and *P. cinctipes*. This was indexed by circulating levels of the yolk protein vitellogenin (Vg). To address the variables, female crabs were exposed to high density (1000 crabs/m2) and low-density (333 crabs/m2) treatments with and without the presence of its congeneric species for 7 days. We found that interspecies interactions in high densities and increased temperature caused a downregulation of vitellogenesis in both *P. manimaculus* and *P. cinctipes*. These results demonstrate the transduction of climate change. Thermal stress in one species is being transduced onto another via increased density and competition in the rocky intertidal ecosystem.

8-8 Scauzillo, RC*; Ferkin, MH; University of Memphis; *rcsczllo@memphis.edu*

Self-grooming with an audience in mind, male meadow voles tailor their behaviors based on social contexts

Terrestrial mammals often acquire mating opportunities through signaling to opposite-sex conspecifics by olfactory means, which can take the form of scent marking and/or self-grooming. These behaviors leave odiferous compounds in the environment that can indicate the signaler's interest in the opposite-sex conspecific(s) as well as the signaler's genotype and current phenotype. The signals can also be placed with those of conspecifics, creating chemical bulletin boards that can provide social information to all individuals who come across it. This can then provide an individual with a range of information that can then affect their own olfactory communication behaviors. We examined how different social odor contexts affected the self-grooming behavior of male meadow

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voles (*Microtus pennsylvanicus*). We used two general social odor contexts of quantity (number of rival odors and acquaintance with rival odor) and one of quality (age of the rival). We found that male meadow voles responded to complex odor situations by adjusting their self-grooming to qualitative aspects of the rivals, but not quantitative aspects of the rivals. By attuning olfactory communication behaviors to social context(s), male meadow voles can adjust the amount of social information provided to both opposite-sex conspecifics and rival same-sex conspecifics. In doing so, male meadow voles can maximize their fitness by signaling at times where the likelihood of being selected as a mate is high and refraining from signaling when the likelihood of being selected as a mate is low.

86-7 Schachner, ER*; Hedrick, BP; Richbourg, HA; Hutchinson, JR; Farmer, CG; Louisiana State University Health Sciences Center, University of California San Francisco, San Francisco, California, Royal Veterinary College, University of London, University of Utah; *eschachner@gmail.com*

Anatomy, ontogeny, and evolution of the respiratory system in Alligator mississippiensis and Struthio camelus

To evaluate the evolution of lungs in archosaurs, it is essential to determine which traits are shared between crocodilians and birds and the role these traits play in the respiratory biology of these lineages. Both groups have unidirectionally ventilated lungs; however, unlike crocodilians which have mobile flexible lungs, the avian respiratory system is functionally and morphologically decoupled with an immobilized gas-exchanging lung, and flexible ventilatory air sacs. To investigate how these two divergent systems evolved, we used traditional and microCT, 3D digital modeling, and morphometry to examine the anatomy of the respiratory system across an ontogenetic series of eleven ostriches (*Struthio camelus*) and ten American alligators (*Alligator mississippiensis*). Left to right asymmetry and intraspecific variation was present in various regions of the bronchial tree in both taxa but was particularly evident in the medial (or cardiac) region of the alligator lung and the caudal aspect of the bronchial tree in both taxa. Five of fifteen lung metrics were significantly different between the two taxa, suggesting that these aspects of the lung are

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more plastic and should be explored in other species. In contrast to previous descriptions of the ostrich, our data demonstrate that regions of the axial skeleton are pneumatized by pulmonary diverticula that emerge directly from adjacent gas-exchanging tissues and not always the air sacs. Interspecific comparisons demonstrate multiple possible homologies between the bronchial trees and overall lung structure, suggesting that certain aspects of the bronchial tree may have been conserved across Archosauria.

16-5 Schaedler, LM*; Taylor, L; Anciães, M; PPG Ecologia, Instituto Nacional de Pesquisas da Amazônia, Manaus, Brazil, Yale University, New Haven, CT, USA; *schaedler.laura@gmail.com*

Delayed plumage maturation in manakins: a review on its patterns and functions

Delayed plumage maturation (DPM) occurs when individuals are sexually mature but don't present definitive plumage patterns. Most manakins present DPM, and juvenile males progressively molt into the definitive plumage across years. Historically, two main hypotheses have been proposed to explain DPM in manakins: female/juvenile mimicry and signaling status. In both, juveniles are more tolerated by adult males in their territories, which could bring benefits as copulations or perfecting courtship displays. The difference is that mimic isn't an honest signal of age, while signaling status is. We review DPM patterns in manakins and evaluate which hypothesis is best supported. DPM seems related to sexual dichromatism, as both traits appear together in manakins. Males usually acquire definitive plumage in 2-3 years, but species with complex hierarchical partnerships may take 4-5. This is interesting as the loss of dichromatism is related to loss of lekking behavior, so species that lek and practice courtship displays would benefit from being accepted in other males' territories to form alliances and perfect displays, especially when successful partnerships are relevant for reproductive success. Also, juveniles can be differentiated from females through plumage and behavioral cues, and suffer less aggression than adults. These data indicate that both juvenile mimicry and signaling status hypotheses are likely to explain DPM in manakins, but not female mimicry as juveniles can be differentiated from females. As variation in plumage stages is high within species, further studies

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are needed to elucidate whether DPM is under physiological control, and if interspecific variation relates to the type of lek.

84-11 Scharf, HM*; Stenstrom, KH; Hauber, ME; Schelsky, WM; University of Illinois at Urbana-Champaign; *hscharf2@illinois.edu*

Heterospecific but not conspecific parasitism delays fledging in host prothonotary warblers

Fledging is a critical stage for avian development with impacts on survival and fitness, yet it remains one of the most understudied components of bird breeding biology. The timing of fledging, what traits predict fledging age, and how brood composition affects fledging age are virtually unknown in most species. The prothonotary warbler (*Protonotaria citrea*) is a cavity-nesting, neotropical migrant that is commonly parasitized by the larger, non-evictor brown-headed cowbird (*Molothrus ater*). The negative effects of cowbird parasitism on warbler nestling growth, physiology, and survival are well-characterized, but it remains unassessed whether the parasite changes the fledging phenology of their host nestmates. Nests were experimentally parasitized with a cowbird egg (n = 19) or warbler egg (n = 14) and compared to non-manipulated control nests (n = 30). RFID (radio-frequency identification) readers were placed on each nestbox and all nestlings were banded with PIT (passive integrated transponder) tags. In 75% of cowbird nests, the parasite fledged first. Whereas parasitism treatment did not affect fledging latency between the first and last fledged chicks, warbler nestlings in the heterospecific but not in the conspecific parasitism nests fledged at significantly older ages (11 vs. 10 days posthatch) compared to controls. Warbler size (a principal component metric from mass, tarsus, and wing length) was smaller in cowbird parasitism nests and predicted the age at which nestlings fledged, with larger nestlings fledging earlier.

65-2 Schatz, A*; McDowell, J; Rivest, EB; Virginia Institute of Marine Science, William & Mary ; *kschatz@vims.edu*

Sub-lethal effects from global environmental stressors on the physiology of Crassostrea virginica during the larval stage and settlement process

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Over diel and seasonal time scales, estuarine organisms like the Eastern oyster, *Crassostrea virginica*, can simultaneously encounter multiple environmental stressors at several stages in their life cycle. While the larval stage is one of the most vulnerable life stages, the process of settlement, a close proxy for metamorphosis, is rarely studied independently as a potential bottleneck for the success of oysters under future climate change. Also, few have studied underlying mechanisms regulating changes in higher-order processes for a more holistic understanding of organismal response to future climate change. We examined effects of multiple stressors on two life stages of oysters and tracked impacts of early exposure on the physiology of later life stages. First, oyster larvae were cultured from fertilization under a factorial combination of two temperatures and two pH values: control temperature and pH, low pH, high temperature, and a multi-stressor treatment. Second, during settlement, oysters were exposed to three pH treatments representing extreme-low, low, and control pH values. Antioxidant defenses, total protein, total lipid, respiration, and growth in both experiments are compared. Increased temperature negatively affected survival early in the larval stage, while later, acidification caused an increase in oxidative stress and decrease in biomass accumulation. Studying effects of multiple environmental stressors for the most vulnerable life phases in oysters and from a holistic perspective provides an understanding of potential plasticity and tolerance to future conditions.

71-10 Scheidt, A*; Geiger, SM; Wagner, FC; Mülling, CKW; Nyakatura, JA; Institute of Biology, Humboldt University of Berlin, Germany, Institute of Veterinary Anatomy, Histology and Embryology, University of Leipzig, Germany; *adrianscheidt@gmail.com*

Sprawling locomotion aspects in a therian mammal? 3-Dimensional forelimb kinematics of Tamandua

Therian mammals are known to move their forelimbs in a parasagittal plane (elbow pointing caudally) while incorporating retraction of a mobilized scapula during stance phase. In non-cursorial therian mammals the elbow is often abducted, extending out of the parasagittal plane at midstance. This is especially prominent in Tamandua (Xenarthra), which suggests they employ aspects of sprawling locomotion. We test whether Tamandua use amphibian- or

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lizard-like sprawling forelimb kinematics (i.e., a largely immobile scapula with pronounced lateral spine bending and long-axis rotation of the humerus), resulting in the salient abducted elbow orientation. We use Scientific Rotoscoping, the non-invasive variant of X-ray reconstruction of moving morphology (XROMM) to provide a detailed description of Tamandua forelimb locomotor kinematics during walking and balancing. The results reveal a mosaic of sprawling and parasagittal kinematic characteristics. The abducted elbow is the result of a constantly inward rotated scapula about its long axis and a retracted humerus. Scapula retraction contributes considerably to stride length. However, lateral rotation in the pectoral region of the spine (range: 21°) is higher than reported for other therian mammals, and is similar to skinks and alligators, indicating an aspect generally associated with sprawling locomotion is part of Tamandua forelimb kinematics. Our study contributes to a growing body of evidence of highly variable non-cursorial therian mammal locomotor kinematics.

61-7 Scheiner, SM; National Science Foundation; *sscheine@nsf.gov*

George Gilchrist: Program Officer

George Gilchrist contributions to evolutionary biology go beyond his research. He served as a program officer at the National Science Foundation from 2009 until his death. During that time he was primarily associate with the Evolutionary Processes program, but also was involved in other activities such as Dimensions of Biodiversity. In this position he promoted the science of evolutionary biology and influenced the careers of many people. His colleagues will describe what he brought to this position and his contributions.

78-6 Schekler, I*; Sapir, N; University of Haifa, Haifa, Israel; *goldinbal@gmail.com*

Quantitative analysis of bird migration over Israel

Israel is located in the heart of one of the largest migration flyways in the world. Yet, the properties of this major migration flyway have only been rarely studied, resulting in a poor understanding of this system. Using data from five consecutive years (2014-2018) collected by three weather radars and eight

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vertical-looking bird radars that were positioned throughout Israel, we investigated the nocturnal avian migration over the country. We applied the vol2bird algorithm to quantify autumn and spring migration properties and examined the meteorological conditions that influenced key migration attributes using the ERA5 model estimates. We found that temperature and tailwind speed were the most influential factors affecting migration intensity in spring, while tailwind speed and overall wind intensity affected autumn migration. Our updated calculations suggest that about 150 million birds migrate through Israel during the autumn, about a third of the amount estimated in previous research in the early 1990s, and we discuss several different reasons for this drastic difference in estimated bird migration volume over the country.

90-10 Schindler, BY*; Gavish-Regev, E; Keasar, T; University of Haifa, Hebrew University of Jerusalem, Hebrew University of Jerusalem, University of Haifa; *brachischindler@gmail.com*
Parasitoid wasp community dynamics in vineyards following insecticide application
In order to integrate parasitoid wasps in agroecosystems as biological control agents, we need to understand how insecticides affect the parasitoids in the crops and their surroundings. We investigated the non-target effect of indoxacarb, an insecticide commonly used against European grapevine moth, on parasitoid wasp communities in wine vineyards. We focused on characterizing: 1. The dynamics of common wasp species, and 2. Wasp abundance and species richness in the vineyard center, edge, and nearby natural area. Five Israeli vineyards, with neighboring natural areas were sampled before, and in the week after, indoxacarb applications. We expected initial negative effects of spraying in the vineyard with some effect of drift in the natural habitat, followed by recovery, first in natural areas, then at the vineyard edge and finally in the center. Sticky traps were hung at the vineyard edge and center to evaluate migration into and out of the vineyard. Vacuum sampling was used to obtain parasitoid total abundance and species richness, and the abundances of four common species (50% of the wasps collected). In the vacuum samples, total wasp abundance and richness declined after spraying in the vineyards' margins and center but rose over time in the natural area. A *Trichogramma* sp.,

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which parasitizes lepidopteran eggs, and was dominant in the vineyard, declined after spraying and did not recover within a week. In the sticky traps, wasps were more abundant at the vineyard edge than center, with no effect of time since spraying. These results suggest that indoxacarb harms (either directly or indirectly) vineyard parasitoids, which use nearby natural habitat as refuge. We found no evidence for recolonization of the vineyards from the non-crop habitat within a week after spraying.

S12-2 Schlinger, BA*; Chiver, I; University of California, Los Angeles and Smithsonian Institute, Panama, Smithsonian Institute, Panama; *schlinge@lifesci.ucla.edu*

Hormonal control of behavioral sex differences in a tropical bird

Hormones organize and activate brain and behavior in sex-specific patterns. Most studies of these phenomena utilize captive animal models and focus on pre-copulatory and copulatory behaviors. We have explored the role of Testosterone (T) in activating a variety of masculine behaviors associated with courtship under semi-wild conditions in the Golden-collared manakin (Manacus vitellinus). For these experiments, we established a large aviary situated within Panamanian rainforest with flora planted to resemble a natural Manacus leking environment. We treated non-breeding females and juvenile males with T and after one week released groups of 3 or 4 same sex birds into the aviary; behaviors were then recorded for at least 3 weeks. With or without T-treatment males cleared and defended courtship arenas, emitted courtship vocalizations and performed their elaborate courtship displays involving wing- & roll-snaps. T increased performance of all behaviors, in some cases dramatically. Females never cleared or claimed arenas and only with T did females perform very few if any wing- or roll-snaps and emit male-like vocalizations. T increased aggressive behaviors equally in males and females. Thus, some male typical behaviors were completely unresponsive to T in females, while others were partially responsive or fully responsive. Presumably, genetic or hormonal differences developmentally create some but not all behavioral neural circuits or create them in all birds but render them androgen-insensitive in females. This work expands our thinking about the ontogeny of complex vertebrate behaviors and

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their control by hormones and invite future studies into the developing manakin CNS.

40-8 Schoenfuss, HL*; Diamond, KM; Lagarde, R; Blob, RW; St. Cloud State University, Seattle Children's Research Institute, Université de Perpignan Via Domitia , Clemson University; *hschoenfuss@stcloudstate.edu*

Ontogenetic change in performance: do innovations constrain performance?

Recent innovations in a species may expand opportunities to obtain new resources or previously inaccessible habitats. Over time, the novel behavior may diversify in response to an adaptive landscape, or alternatively may become canalized to a narrowed performance window. Selective pressures also change across life stages, which may further enhance diversification or constraint of locomotor performance. To test these alternative hypotheses, we investigated seven amphidromous species of waterfall-climbing gobies across the Pacific, Caribbean, and Indian Oceans. Two species climb waterfalls using an inching motion, a derived functional innovation that alternates movements of pelvic and oral suckers. The remaining species climb waterfalls using short bursts of swimming, followed by long rest periods in which the pelvic sucker is attached to the waterfall substrate. Climbing speed during locomotion was significantly greater in all burst climbers, but absolute speed that factored in rest periods was more similar between climbing styles. Kinematic analyses revealed greater diversity in the critical locomotor behaviors of burst climbers (e.g., fin excursion angles) than among those of inching climbers (e.g., mouth area). These findings mirror observations in juvenile climbers and suggest that functional diversity may be masked when similar performance is achieved through multiple pathways. This study illustrates that biogeographic studies of novel functional behaviors provide opportunities to assess how adaptive landscapes modulate innovation over time.

84-6 Schoepf, I*; Olson, S; Moore, IT; Bonier, F; Queen's University, Virginia Tech; *ivana.schoepf@queensu.ca*

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Experimental evidence of haemosporidian infection effects on maternal care behavior in a wild passerine

Parasites can impose substantial fitness costs on their hosts. At energetically demanding life-history stages (e.g., during reproduction), their effects may be particularly taxing. In species with parental care, offspring rearing can be very costly for parents, and especially so, if they are burdened by infections. Vector-borne haemosporidians are some of the most widespread endoparasites. Haemosporidians can affect their hosts in several ways, including the ability of parents to care for their young. Costs of infections are, however, not consistent across species, with correlational and experimental studies showing contrasting effects of infections on parental care behavior. Most research has, however, been conducted in systems with chronically low infection levels. Here, we present the results of a study we conducted in a free-ranging population of red-winged blackbirds (*Agelaius phoeniceus*) naturally experiencing unusually high haemosporidian infection levels. At our field site in south-eastern Ontario, >90% of individuals are parasitized with one or more haemosporidian genus. To assess effects of infection on mothers' abilities to incubate and provision their offspring, we caught adult red-winged blackbird females before onset of egg-laying and experimentally manipulated their parasite levels by administering either an anti-malarial medication or a control solution. Our results provide experimental evidence that reduced haemosporidian burdens lead to increased maternal care behavior, supporting the idea that parasitic infections reduce fitness even in populations with chronically high infection levels.

95-9 Schott, RK*; Bell, RC; Ellis, LR; Thomas, KN; Streicher, JW; Gower , DJ; Fujita, MK; York University, Toronto and National Museum of Natural History, Washington DC, California Academy of Sciences, San Francisco, Cornell University, Ithaca, Natural History Museum, London, University of Texas, Arlington; *schott@yorku.ca*

Visual adaptations in the transition from aquatic to terrestrial light environments in the life cycle of southern leopard frogs

Most frog species rely on vision as both tadpoles and adults, and thus the visual system changes to function optimally in the

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different light environments they inhabit across ontogeny. At metamorphosis, the eyes typically change size and position, along with changes in retinal circuitry, morphology, and sensitivity. The genomic basis of these changes, however, is poorly understood. We used whole eye transcriptome sequencing to investigate differential expression between aquatic tadpoles and terrestrial juveniles of the southern leopard frog and the effect that short-term (12h) exposure to light or darkness has on expression patterns. We found that many genes were differentially expressed in the eyes of tadpoles versus juveniles, while light/dark exposure had a relatively minor effect. Analyses targeting visual genes revealed significant differential expression between life stages in genes that control aspects of visual function and development including spectral sensitivity and lens composition. Light/dark exposure had a significant effect on a small subset of visual genes. Finally, microspectrophotometry of photoreceptors confirmed shifts in spectral sensitivity predicted by the expression results. Overall, we identified extensive expression-level differences in the eyes of tadpole and juvenile frogs that likely underlie observed morphological and physiological changes through metamorphosis and corresponding adaptive shifts to optimize visual ability in aquatic versus terrestrial light environments.

7-4 Schultz, JT*; Cieri, RL; Proost, T; Clemente, CJ; 1. University of the Sunshine Coast, QLD, Australia 2. CSIRO Data61, QLD, Australia , University of the Sunshine Coast, QLD, Australia ; *johanna.schultz@research.usc.edu.au*

Comparative biomechanics of lizard tails during level walking and vertical climbing

Tail movement is an important component of vertebrate locomotion, and likely contributes to dynamic stability during steady-state locomotion. Many studies have investigated specific aspects of tail biomechanics in lizards, but a comprehensive study of tail motion during locomotion in lizards of different masses, body shapes, and habitats has not been conducted. Multiple studies in lizards found decreased sprint speed and stability after tail loss. These decreases depended on species but not habitat and were more substantial in lizards with larger tails. Other studies highlighted the role of the tail for transitioning into bipedal locomotion or

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for active pitch-control during jumping. These results suggest that the tail plays a significant role in lizard locomotion, but little data are available on tail motion during locomotion and how it differs with morphological, ecological, and phylogenetic parameters. We collected high-speed vertical climbing and horizontal locomotion video data from 52 lizard species from 4 taxonomic groups (Agamidae, Gekkota, Scincidae, Varanidae) and 4 habitats. Tail motion was quantified using markerless pose-estimation, deep learning for outline/shape detection and automated visualisation. In geckos, the tail base and mid tail viewed dorsally moved sinusoidally in opposite phase, and the tail tip reached peak lateral displacement when the tail base and mid tail were aligned along the body axis. These results will provide general insights into the biomechanics of tails in sprawling locomotion enabling biomimetic applications in robotics, and a better understanding of vertebrate form and function.

6-5 Schulz, A*; Seleb, B; Wallace, R; Hu, D; Georgia Tech, School of Mechanical Engineering, Atlanta, GA, Georgia Tech Research Institute ; *akschulz@gatech.edu*

Conservation technology through multidisciplinary undergraduate teams

At Georgia Tech we teach a team-based design course, GaTech4Wildlife, which manages interdisciplinary teams to work on technology to support wildlife conservation. This course is part of the Vertically Integrated Projects program, which gives students opportunities to engage in long term interdisciplinary projects spanning several years. Since its inception, our course engaged 30 students from 14 different majors. Each team comprises 4-5 students, which allows a range of majors to round out each team's skill set. Through journal club, case studies, and traditional lectures, students build a groundwork in conservation technology and apply it through projects carried out at partner locations such as Zoo Atlanta. Current projects include designing an automated foraging device for primates, organizing a rabies vaccination biscuit distribution network for urban carnivores, and creating a carbon neutral indigo snake reintroduction center. This course connects biology experts to engineering students and creates open source instruction so this course can be implemented nationwide.

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19-3 Schuppe, E*; Catin , L; Biegler , M; Jarvis, E; Fuxjager, M; Cornell University, Ithaca, NY, The Rockefeller University, New York, NY, Brown University, Providence, RI; *es987@cornell.edu*
Neural correlates of drumming behavior in free-living woodpeckers
Gesture is one of the most ubiquitous forms of communication in the animal kingdom. However, little is known about the motor circuits that control such behavior. One possibility is that neural control of gesture might arise through repurposing and specializing ancestral circuits that control other forms of communication, which has been proposed to occur for circuits in some bird species through brain region or pathway duplications of an ancient motor learning pathway. We investigated the brain regions that control woodpecker drumming. We used a set of conserved molecular markers typically expressed in brain areas that control learned vocalizations in oscines. This approach identified two forebrain nuclei that exhibit striking neuroanatomical and molecular similarity to those found in the avian song system—the RA and LMAN, respectively. Both areas showed increased neural activity (immediate early gene) induced expression when birds drummed during territorial interactions, but not when they vocalize or move around during these interactions. Similar substrates also exist in the brains in two distantly related woodpecker species that also drum. Thus, we uncovered putative forebrain substrates associated with the production of an elaborate gestural display in the downy woodpecker, which may be shared across the woodpecker phylogeny. We suggest that ancestral forebrain circuits that control and refine motor patterns for communication, including those that gave rise to song control system in oscines, may be repurposed for drumming in woodpeckers. In both cases, communication may underlie the evolution of innovation, such as elaborate gestural displays that mediate aspects of socio-sexual behavior.

68-11 Schutz, H*; Jamniczky, HA; Anderson, RJ; Warwick, EG; Barry , TN; Pacific Lutheran University, WA, University of Calgary, Canada, University of Notre Dame, IN, University of Lethbridge, Canada; *schutzha@plu.edu*

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Beyond the binary: sexual variation in threespine stickleback (Gasterosteus aculeatus l.)

Sexual dimorphism is understood as the result of sexual selection, ecological differentiation between the sexes, or a combination of both. Sexual variation is subject to the uniform genetic architecture controlling sexually homologous traits. This interplay may both constrain the evolution of this variation and provide a pathway to speciation and intraspecific diversity. Describing sexual variation as "dimorphism" overly simplifies the mosaic nature of the effects of selective pressures on organisms. Not all traits in a species display sexual variation and when variation exists in multiple phenotypic traits, it is often non-uniform. Moreover, selection driving sexual variation influences phenotypic variation not directly associated with genotypic sex. This important component of phenotypic variation is often lost in discussions focusing solely on a statistically significant binary. Threespine stickleback (*Gasterosteus aculeatus*) display rapid adaptive responses and sexual variation in several phenotypic traits, ranging from body size to cranial shape. The presence, magnitude and direction of sexual variation in these traits varies greatly both within and across habitats. Using 3D geometric morphometrics, we quantified shape and size of the cranial, pectoral and pelvic regions of sticklebacks in marine and freshwater habitats from southwestern B.C. We show varying degrees of sexual variation in body regions, in habitats, within sex, and habitat-dependent modulation of sex effects on morphology.

2-5 Schwaner, C*; Farhat, S; Tanguy, A; Boutet, I; Barbosa, M; Pales Espinosa , E; Allam, B; Stony Brook University, Stony Brook, NY, Station Biologique de Roscoff, France , Station Biologique de Roscoff, France ; *caroline.schwaner@stonybrook.edu*

Identifying molecular markers associated with resilience to ocean acidification in the eastern oyster

Natural genetic variation is a valuable source of resilience to changing environments. The eastern oyster (*Crassostrea virginica*) lives in spatio-temporally highly variable environments. This species is able to survive in a wide variety of environments due to its physiological plasticity, evolutionary adaptation to specific environments, or both. It is well-recognized that the evolution of

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resilience to climate related stressors depends on the standing stock of genetic variation. This study aimed at the identification of molecular pathways associated with oyster resilience to ocean acidification (OA). Adult oysters were spawned and larvae were reared in ambient (pCO_2 of ~600 ppm) or acidified (~1200 ppm) conditions immediately upon fertilization. RNA and DNA samples were collected before larvae were moved to pCO_2 treatments, after 96 hours in treatments, and after metamorphosis. Samples were processed for gene expression using RNASeq and SNP profiling by ddRADSeq. Detected variants from survivors of OA were related to biomineralization, calcium ion binding, cell differentiation, ion channel activity and hemocyte function. Upregulated genes under OA conditions included genes related to the above functions as well as response to stress. Downregulated genes were involved in immunity and cell signaling. Overall, metamorphosis appeared to be more of a selective pressure than larval development. This research indicates that resilience to OA is at least partially dictated by genetics.

S5-1 Schwaner, MJ*; Hsieh, ST; McGowan, CP; University of Idaho, Moscow, ID, Temple University, Philadelphia, PA; *janneke.schwaner@gmail.com*

Introduction to an evolutionary tail: Evodevo, structure, and function of post-anal appendages

Tails are extremely versatile appendages that contribute to the evolutionary success of animals in a remarkable range of ways. Just to name a few: They play keys roles in mating displays, territorial disputes, and mediating predator-prey interactions. They can also be reduced, elongated, prehensile, round or angular, or covered in spines. Tails are fundamental to locomotion in animals as well as bio-inspired robotic designs, providing propulsion in water, balance on land, and grasping in trees. They are common to all chordates and analogous structures have arisen convergently in numerous invertebrate species. Yet compared to appendages such as legs, tails are vastly understudied. Despite their evolutionary significance, we know relatively little about their development, morphological diversity, or mechanical function. In contrast to other parts of the body (i.e., limbs or parts of the axial skeleton other than the tail), tails have not yet been the focus of a scientific synthesis to bring to bear the power of integrative and

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comparative approaches. Yet, the simple fact that they persist as a common structure of the basic animal body plan emphasizes their evolutionary importance. This symposium will bring together diverse researchers examining the breadth of tail structure and function, with the goal of stimulating new directions for study. We will assemble behavioral and evolutionary biologists, ecologists, biomechanists, computational biologists, and roboticists to discuss the breadth and similarities among tail use and shape. These presentations will provide new insight and synergies among scientists across disciplines who otherwise may not normally interact and allows for the first time a larger framework for research on tail evolution, form, and function.

S5-6 Schwaner, MJ*; Freymiller, GA; Clark, RW; McGowan, CP; University of Idaho, Moscow, ID, University of California San Diego, San Diego, CA; *janneke.schwaner@gmail.com*

How kangaroo rats utilize their tail while re-orienting

To avoid predation by snakes, kangaroo rats (D. deserti) use ballistic vertical leaps - up to over ten times their hip height. While airborne, these animals change their orientation. Simultaneously, they move their tail through the air, bending and twisting it around and over the body. These observations suggest that kangaroo rats utilize their tail for not only balancing their body while airborne, but also to facilitate body re-orientation. To test this hypothesis, we collected three-dimensional video data on kangaroo rats exhibiting a predator escape response to a self-built, artificial predator attack simulator. From these video data we quantified angular momentum of the tail and the body in the yaw-plane (rotation around the vertical axis). Preliminary data suggest that tails do play an important role in balancing and orienting kangaroo rats while airborne, as body angles of escaping rats show a step-wise re-orientation. While all tail segments are closest to the body's rotation axis (up or down in the air, low tail moment of inertia in z-plane), the body orientation change is minimal. This is typically followed by an increase in tail moment of inertia as the tail is sweeping away from the body, during which the body orientation changes again. Body rotation typically goes through 2 to 4 orientation steps while airborne. Time airborne, jump height, and jump distance do not correlate with number of orientation

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steps. This suggests that this step-wise re-orientation is created by tail movement, as legs are tucked under the body during this aerial period. Further investigation of 3D tail parameters will elucidate how the kangaroo rat utilizes its tail to facilitate aerial re-orientation of the body.

34-8 Schwartz, NL*; McNamara, MP; Rashid, JO; Garland Jr, T; University of California, Riverside; *nschw002@ucr.edu*

Selective breeding for voluntary exercise partially supports the aerobic capacity model for the evolution of endothermy

The aerobic capacity (AC) model for the evolution of vertebrate endothermy posits that selection for high sustained activity levels required increased maximal oxygen consumption (VO2max), and that increased basal metabolic rate (BMR) evolved as a correlated response, such that VO2max/BMR remained relatively constant. A correlated response in BMR is based on presumed causal, mechanistic links (e.g. shared biochemical or physiological pathways) with VO2max that have yet to be identified. The AC model has also been considered more generally with respect to vertebrate energetics. The literature offers mixed support for the AC model. We tested the hypothesis that selection for daily activity levels in mice, which is known to have increased VO2max (and endurance capacity) during forced treadmill exercise, has also elevated BMR. We measured VO2max, BMR, and organ masses of 50 females from generation 88 of an ongoing experiment in which 4 replicate lines of High Runner (HR) mice are bred for daily running distance and compared with 4 non-selected Control (C) lines. With body mass as a covariate, HR mice had a significantly elevated VO2max (+14%), as reported in several previous studies, and also a significantly elevated BMR (+8%). These results are partially consistent with the AC model, as the increase in BMR was somewhat less than for VO2max. Although higher VO2max is often associated with larger hearts, lungs, muscles, and increased hematocrit, HR mice from this sample were not statistically higher for any of these traits. As well, BMR should be positively associated with the relative size of heart, brain, liver, kidney, and spleen, but again HR mice did not differ from C for any of these organ masses (with body mass as a covariate).

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52-13 Schwartz, ST*; Tsai, WLE; Karan, EA; Alfaro, ME; University of California, Los Angeles; *shawnschwartz@ucla.edu*

Charisma: An R tool to automatically determine discrete color classes for high-throughput color pattern analysis

The charismatic color patterning of organisms has captivated scientists for decades. Animal colors and patterns are important to study as they serve ecologically important functions for communication through sexual or social signaling, and provide crypsis, advertisement, or mimicry. Recent conceptual advances have facilitated the ability to perform a variety of color pattern analyses without needing expensive spectral photography equipment, multispectral images of specimens, nor photoreceptor curves for taxa; hence, we can now use standardized, high fidelity image sets of specimens already accessible to researchers to perform high-throughput studies of color pattern. Yet, many popular color pattern analysis pipelines are halted by requiring users to input the number of dominant color classes (k) before computing color pattern geometry measures. For large-scale analyses, objectively determining k can be cumbersome and inconsistent for groups with wide color class disparity between taxa. Previous studies have avoided this bottleneck by choosing one, overarching k-value to account for the typically observed variation within that group; however, this naive approach fails to account for differences in color pattern geometry statistics when intragroup color diversity is large. Here, we present charisma, an R tool to automatically determine the number of distinct color classes within an image or image set, substantially limiting the need to generalize k for large-scale color pattern analysis. Our toolkit utilizes flexible parameters to yield reproducible, objective, and customizable results for a diverse range of problems, and is designed to work seamlessly with popular color pattern analysis packages (e.g., pavo, patternize).

2-9 Schwartz, LC*; Truebano, M; Strong, EE; Hilbish, TJ; González, VL; The University of South Carolina at Columbia, University of Plymouth, Plymouth UK, Smithsonian Institution, Washington, DC, Smithsonian Institution, Washington, DC; *schwarl@email.sc.edu*

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Thermal tolerance in the Mytilus species complex across multiple levels of biological organization

Temperature is one of the most important abiotic factors affecting the performance of ectotherms, and in the context of climate change, there has been renewed interest in thermal physiology. Climate change has already resulted in range shifts of many marine and terrestrial species, including the blue mussel (genus *Mytilus*). The blue mussel species complex is comprised of the congeners *Mytilus trossulus, M. edulis*, and *M. galloprovincialis*, which replace each other as temperature increases. Here we consider the cold-temperate *M. edulis* and the warm-temperate *M. galloprovincialis* and their hybrids. The two parent species are physiologically and genetically distinct yet retain the ability to produce viable hybrid offspring. In this study we sampled individuals in and around a hybrid zone in southwest England and acclimated them to either 15° C or 23° C for 14 days in order to evaluate their response to persistent, lower level warming. Physiological results support previous studies suggesting feeding rate and energy limitation as the mechanisms for lower heat tolerance in *M. edulis*. In both respiration rate and feeding rate, there is a significant interaction between genotype and temperature. Initial transcriptomic results, however, suggest that genotype, rather than temperature, is the main source of variance among the individuals. In addition, very few genes responded differently to temperature depending on genotype, suggesting that there may be limited intra-specific plasticity in gene expression when it comes to thermal tolerance genes. Energetics analyses are currently underway to examine energy stores and other metabolic indicators in these samples.

38-1 Schwarz, R*; Stark, G; Antonopolous, A; Itescu, Y; Pafilis, P; Chapple, DG; Meiri, S; Tel Aviv University, Israel, National and Kapodistrian University of Athens, Greece, Freie Universität Berlin, Germany, National and Kapodistrian University of Athens, Greece, Monash University, Clayton, Victoria, Australia, The Steinhardt Museum of Natural History, Tel Aviv University, Israel; *rachelschwarz13@gmail.com*

Master of one or none: Functional morphology and microhabitat preference of arboreal and saxicolous gecko populations

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Populations occupying different microhabitats can either exhibit generalized traits across habitats or show intra-specific variability, adapting to each microhabitat to maximize performance. Intraspecific variability is important for studying evolutionary mechanisms promoting diversity and adaptation. Despite its importance, intra-specific variability is relatively little studied compared to variation between species occupying different habitats and microhabitats. We investigated whether populations of the gecko *Mediodactylus kotschyi*, that differ in the substrates they occupy, display microhabitat specific behaviour and functional morphology. We collected geckos from seven populations in Greece, under or on rocks or on trees. We tested their microhabitat preference and clinging ability in the lab. We measured the limb, digit, and claw morphometrics of geckos and examined their relationship to clinging ability. Geckos showed no preference to either substrate, regardless of the substrate on which they were found, or the availability of trees in their natural habitat. All geckos clang better to the tree, but the same claw morphology: shorter and higher claws, was associated with better clinging to both substrates. Our results suggest that although *M. kotschyi* cling better to trees than to rocks, their morphology enables them to occupy both substrates, a fact that may have aided them to inhabit the smallest, treeless islets in the Aegean Sea.

93-6 Schweikert, LE*; Thomas, KN; Moreno, VM; Casaubon, A; Golightly, C; Bracken-Grissom, HD; Florida International University, Natural History Museum, London, England, Florida Institute of Technology, Tennessee Technological University; *lorian.schweikert@gmail.com*

Ecological predictors of eye size in deep-sea shrimp

Eye size is fundamental to vision in that increasing size improves photon capture, leading to the enhanced ability to detect light. Due to the high metabolic cost of maintaining eyes, considerable size variation is observed among animals and can serve as an indicator of the importance of vision. In the deep sea, constraints on energy resources and ambient light place strong selection pressure on eyes, providing a unique opportunity for studying the ecological correlates of eye size evolution. Here, we examined eye size across 454 specimens of 15 species of Sergestidae shrimps, in

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order to test hypotheses about the relationship of eye size to light organ morphology, vertical migration behavior, and depth. Examining eye-to-body size scaling over growth, we found significant variation in allometric slopes between species, suggesting varying degrees of eye investment for a given body size that align to differences in phylogeny and ecology. To correct for phylogeny, we used a phylogenetic generalized least squares approach to determine the ecological correlates of average eye size between species. We found that eye size (corrected for body size) is at least predicted by interspecific differences in light organ morphology, suggesting that investment in eye size may be driven by differences in bioluminescence signaling. Overall, our study provides new insights into eye size evolution, helping to disentangle the phylogenetic, morphological, and ecological constraints that underlie vision in the deep sea.

32-6 Scott, CB*; Toth, L; Rohland, N; Mah, M; Reich, D; Matz, M; University of Texas, Austin, TX, U.S. Geological Survey, St. Petersburg Coastal & Marine Science Center, St. Petersburg, FL, Harvard Medical School, Boston, MA, Harvard Medical School, Boston, MA and Broad Institute of Harvard and MIT, Cambridge, MA; *cbscott@utexas.edu*

Ghosts of coral past: Applications of ancient dna methodology to carribean coral reef cores

To better understand the history of coral reef ecosystems, we sequenced DNA from Carribean *Acropora palmata* reef cores dated to ~1000 years old. The project sought to answer two questions: 1) Is it possible to sequence aDNA from coral reefs, and, 2) what does this data tell us about coral ecosystems of the distant past? While we did not find any coral aDNA reads in the cores, we successfully recovered ~100,000 (0.2% overall) *Symbiodinacea* reads from each sample. To determine the authenticity of these reads we looked for patterns of damage characteristic to ancient DNA, such as rate of C to T substitutions at the 5’ end of mapped reads. Our data matched these expectations and was distinct from the patterns seen in modern day *Symbiodinacea* reads. By assigning the reads to the species level, we found the predominant symbiont to be *Cladicopium spp.* This is surprising, as present-day *A. palmata* associates with *Symbiodinium spp.* Given the sensitive nature of coral-

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zooxanthellae symbiosis, this shift may signal key ecological changes. Further, by applying metagenomics approaches, we assigned an additional ~0.2% of the reads to the phylum *Rhodophyta*. Half of these reads belonged to the order *Corallinales* (crustose coralline algae) - a key organism promoting coral larvae settlement. Overall, the sequencing of reef matrix aDNA identified ancient organisms at the species level, though lack of read coverage across putative genomes limited further analysis.

98-9 Sellers, KC*; Clark, JM; Middleton, KM; Holliday, CA; University of Missouri, George Washington University; *kcsty5@mail.missouri.edu*

Skull shape, muscle orientation, and joint loading in a biomechanical transformation: Evolution of the suchian skull

The evolution of crocodylian high-performance biting involved a reorganization of the feeding apparatus. Whereas modern crocodylians have flat, robust skulls, crocodylian ancestors had tall skulls and lacked the characters that help crocodylians employ high forces. To assess the biomechanical effects of changing muscles and cranial joints, we used CT data to create 3D models of extant and fossil suchians. Using osteological correlates to reconstruct muscles, muscle forces were distributed and used as input for finite element models and used to estimate bite and joint forces. Geographic information systems were adopted to quantify joint articular shape. We found successive changes to cranial joints preceded muscle shifts. After the pterygoid buttress expanded and the quadrate and palate sutured to the braincase in protosuchians, jaw muscles were free to expand and shift attachments through crocodyliform evolution. Muscle orientations became more mediolateral as the skull flattened, the pterygoideus ventralis muscle began inserting on the lateral mandible, and the depressor mandibulae muscle expanded its attachment on the enlarged retroarticular process. We found that working side jaw joint force is low during rostral bites; the joint is likely loaded in tension during shaking or the death roll. Joint area and force scale isometrically with body size, and joint force orientation is reflected in joint morphology. Joint pressures are remarkably consistent both with values reported in other in vivo and in vitro joint systems and with the range of joint pressures predicted to

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result in stable joint morphology by chondral modeling theory. These results depict coordinated coevolution of skull shape, muscle orientation, and joint loading in one of the great transformations in vertebrate evolution.

84-13 Senécal, S*; Riva, JC; O'Connor, RS; Nozais, C; Vézina, F; Université du Québec à Rimouski; *Sarah.Seneca1@uqar.ca*

Chickadees increase provisioning effort to compensate for poor prey quality during the nestling period

In altricial avian species, nutrition can significantly impact nestling fitness by increasing chances of survival and recruitment after fledging. Therefore, the effort invested by parents towards provisioning nestlings is crucial and represents a critical link between habitat resources and reproductive success. Recent studies suggest that provisioning rate has little or no effect on nestling growth rate. However, these studies do not consider prey quality, which could force breeding pairs to adjust provisioning rates to account for variation in prey nutritional value. In this eight-year study using black-capped (Poecile atricapillus) and boreal chickadees (Poecile hudsonicus) as model species, we hypothesized that provisioning rates would negatively correlate with prey energy content across years as parents adjust their effort to maximise nestling growth rate. Mean daily growth rate was consistent across years in both species. However, prey energy content differed among years, and our results showed that parents brought more food to the nest and fed at a higher rate in years of low prey quality. This compensatory effect likely explains the lack of a relationship between provisioning rate and growth rate often reported in this and other studies. Therefore, our data support the hypothesis that parents increase provisioning effort to compensate for poor prey quality, thereby maintaining optimal nestling growth rate.

18-3 Sepúlveda-Rodríguez, G*; Lauder, GV; Di Santo, V; Stockholm University, Sweden, Harvard University, Cambridge, MA; *guasepulvedar@gmail.com*

Effect of speed on collective behavior in schooling and shoaling fishes

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Collective behavior arises from the interactions among a group of individuals particularly during locomotion. In social fishes, this collective behavior is manifested either in stable formations, where individuals maintain precise relative positions, i.e. a school, or in a group of individuals swimming together in a loose aggregation, i.e. a shoal. Both behaviors are thought to decrease energy expenditure during swimming as social fishes benefit from the presence of conspecifics. However, it is unclear if schooling fishes may acquire additional advantages when compared to shoaling fishes by swimming in geometrically specific formations. Here we present kinematics and dynamics during collective behavior at different speeds in an obligate schooling species, the Inland silverside *Menidia beryllina* and a shoaling species, the giant danio *Devario aequipinnatus*. For both species we chose individuals of about 5cm in length. We used high speed cameras to reconstruct kinematics of collective behavior of groups of fishes at speeds between 1-15 BL/s. In particular, we quantified fish position and stability through time of this position in the school, body angle, tail beat frequency, amplitude and body curvature across all speeds. One of the most important results from this study is that as speed increases, obligate schoolers tend to maintain a stable formation, while the shoaling species breaks up the group as individuals switch position much more frequently.

92-2 Serrano-Rojas, SJ*; Pašukonis, A; Stanford University; *shirley.serrano25@gmail.com*

Do tadpole-transporting frogs use stagnant water odor to find pools in the rainforest?

Breeding sites are scattered, ephemeral, and limited resources for rainforest amphibians. This resource limitation has driven the evolution of a variety of reproductive strategies across species to enhance larval development and maximize offspring survival. For example, most poison frogs shuttle their tadpoles from terrestrial clutches to aquatic rearing sites using various cues to assess pool suitability. Yet, the sensory mechanisms and strategies involved in finding new pools are not well understood. In this study, we worked with the poison frog *Allobates femoralis* to test the role of odor cues in the process of finding new tadpole deposition sites. We placed 60 artificial pools in the field grouped into three

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conditions: (1) stagnant water odor cues, (2) presence of conspecific tadpoles, and (3) clean water control. Out of the 60 pools, fifteen (25%) were discovered within six days and frogs showed a clear preference for stagnant water odor cues. Out of 253 tadpoles deposited in 15 artificial pools, 212 tadpoles were deposited in 11 stagnant water odor pools, 23 tadpoles in two pools with conspecific tadpole cues, and 18 tadpoles in two control pools. Furthermore, of the 18 frogs directly observed at the pools (of which, four were transporting tadpoles), 15 were at stagnant water odor pools, two at pools with conspecific tadpole cues, and one was at the control pools. Our data suggest that frogs are using odor cues for the initial discovery of new tadpole rearing pools. These odor cues may be important indicators of pool stability and increased likelihood of tadpoles' survival.

1-5 Seymoure, BM*; Parrish, T; Egan, K; Irwin, D; Crooks, K; Angeloni, L; Living Earth Collaborative, Washington University, Colorado State University; *brett.seymoure@gmail.com*

Moth Survival Increases Under High Pressure Sodium Lights

Anthropogenic light at night is growing spatially and in intensity globally while insects are on a global decline. Many nocturnal insects provide numerous ecosystem services and are attracted to anthropogenic lights at night resulting in decreased fitness, greater mortality and population declines. During crepuscular and night hours, moths are depredated by bats and birds, both of which are using vision to detect and prey upon moths. The visual detection of moths by predators is dependent upon the light environment illuminating the moth's body, and anthropogenic light at night can differ drastically in the color (spectral composition) and intensity of light. Currently, High Pressure Sodium Lamps (HPS) and Light Emitting Diodes (LEDs) are the main light sources used by municipalities and these lights differ in spectral composition with LEDs being broad band and HPS being dominant in longer wavelengths of light (red-shifted). Using plasticine clay models of moths, we tested the survival of moths under different light sources (HPS and LED) as well as under no direct lighting in an urban setting to show that moths are more likely to survive under HPS lighting than LEDs and non-lit poles. Visual model analyses reveal that HPS lamps render moths more cryptic against their background than LEDs or

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ambient urban lighting. Although these results indicate that HPS lighting is the most insect friendly lighting, we further show that the artificial visual environment created by HPS is more likely to make prey detection by birds difficult and could perhaps shift an evolved visual predatory-prey dynamic in urban settings.

51-9 Shah, AA*; Hamant, EL; Woods, HA; University of Montana; *alishas0624@gmail.com*

Species interactions and climate change: does thermal tolerance determine winners and losers?

To understand organismal response to rapidly change climate, many studies measure thermal tolerance in populations of single species. However, species do not exist in isolation, and their responses to novel climates will be determined by temperature-mediated interactions with other species. Thus, if interacting species differ in thermal sensitivity, shifts in community composition and dynamics will occur as environments warm. Still, studies that measure thermal tolerance in interacting species under similar conditions are rare. We examined how changing temperature could alter interactions between an insect host (leaf-mining caterpillar) and one of its major predators (wasp parasitoid). In the wild, adult wasps lay eggs on miners pupating in aspen leaves. After hatching, larval wasps consume the miner and eventually emerge as winged adults. Whether temperature mediates wasp-miner interactions remains unknown. We measured miner and wasp development rates across temperatures and thermal tolerance limits (CTmax, LT50). In the development experiment, aspen leaves containing leaf miner pupae and wasp eggs were held for 30 days in temperature-controlled incubators that mimicked cold, normal, and hot spring temperatures. Leaf miners developed and emerged as moths sooner than wasps in the coldest treatment (15 °C), but later than wasps in the warmest treatment (35 °C). In the heat tolerance experiments, caterpillars generally tended to be more tolerant than wasps. Our results suggest not only that thermal sensitivity varies between host and parasitoid, but which species 'wins' or 'loses' might depend on the life stage at which thermal stress occurs.

80-4 Shah, K*; Hardiman, E; Shehaj, A; Konow, N; University of

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Massachusetts Lowell, Lowell, MA; *krina_shah@student.uml.edu*

In-vivo muscle-tendon unit length-change for the mouse soleus and tibialis anterior

During movement, muscles undergo combinations of active and passive shortening and lengthening. We measured muscle-tendon unit (MTU) length-change by proxy of ankle kinematics across nine gait-slope combinations for two monoarticular muscles in the mouse, Soleus, and Tibialis anterior. Markers on the shin, ankle, and foot were digitized to calculate the ankle angle. Tendon-travel experiments were used to measure moment arms (*r*) for both muscles. Soleus *r* was 0.033 mm/degree and Tibialis anterior *r* only -0.01 mm/degree. Based on these values, we calculated muscle length-change trajectory as L_{MTUmin} + (&theta$_{ankle}$ x r), to obtain realistic MTU excursions for forthcoming work-loop experiments. Mean length-change varied across gait-slope combinations. Regardless of gait (walk, trot, or gallop), mean shortening was greatest during uphill locomotion (Soleus: -0.98 ± 0.18 mm, Tibialis Anterior: -0.39 ±0.019mm: mean ± S.D.). The combinations resulted in net muscle shortening during stance with most gait-slope combinations involving around approx. 1 mm (for Soleus) and 0.3mm (for Tibialis Anterior) muscle shortening (approx. 10% strain for Soleus and 3% for Tibialis anterior), whereas level walking only involved 0.13 ± 0.02 mm MTU shortening for Soleus. The work-loop technique traditionally involves sinusoidal or saw-tooth length-trajectories, which differ significantly from the non-monotonic length-trajectories that MTU's undergo *in-vivo*. With *in-vivo* length-trajectories for the two MTUs calculated, we can now determine how a muscle produces power and work *in-vivo*, and how these power and work outputs differ from those estimated using the simpler length-trajectories traditionally used for work-loops.

53-4 Shankar, A*; Davalos, LM; Powers, DR; Graham, CH; Cornell University, Ithaca NY and Stony Brook University, Stony Brook NY, Stony Brook University, Stony Brook NY, George Fox University, Newberg OR, Swiss Federal Institute WSL Birmensdorf Switzerland and Stony Brook University, Stony Brook NY; *nushiamme@gmail.com*

Energy budgets to explain allometry: lessons from flying ninja hummingbirds

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Groups with unusual allometric relationships can provide new avenues for physiological and ecological research. According to the metabolic-level boundaries hypothesis, metabolic rates as a function of mass are expected to scale closer to 0.67 when driven by surface-related processes (e.g. heat or water flux), while volume-related processes (e.g. activity) generate slopes closer to one. In birds, daily energy expenditure (DEE) scales with body mass (M) with a slope of 0.68, consistent with surface-level processes driving the relationship. However, taxon-specific patterns differ from the scaling slope of all birds. Hummingbirds have the highest mass-specific metabolic rates among all vertebrates. Previous studies on a few hummingbird species, without accounting for the phylogeny, estimated that the DEE-body mass slope for hummingbirds to be 1.21. In contrast to theoretical expectations, this slope >1 indicates that larger hummingbirds are less metabolically efficient than smaller hummingbirds. We collected DEE and mass data for 12 hummingbird species, which, combined with published data, represented 17 hummingbird species in eight of nine hummingbird clades over a six-fold size range of body size (2.7-17.5 g). After accounting for phylogenetic relatedness, we found DEE scales with body mass with a slope of 0.96. This slope of 0.96 is lower than previously estimated for hummingbirds, but much higher than the slope for all birds (0.68). The **high slopes of torpor, hovering and flight potentially explain the high interspecific DEE slope for hummingbirds** compared to other endotherms.

81-10 Sharma, A*; Grebe, NM; Freeman, SM; Bales, KL; Patisaul, HB; Drea, CM; Duke University, Durham, NC, University of California, Davis, University of California, Davis, North Carolina State University, Raleigh; *annika.sharma@duke.edu*

Comparative oxytocin and vasopressin neurocircuitry in relation to mating system in Eulemur

Contemporary theory on the role of oxytocin and vasopressin in mammalian social bonds has been shaped by seminal vole research that revealed interspecific variation in neuroendocrine circuitry by mating system. The *Eulemur* genus of strepsirrhine primates contains socially monogamous (MO) and non-monogamous (NM) species, making it the sole primate analog to *Microtus*, and offering a rare opportunity for comparative nonapeptide research with greater

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evolutionary relevance to humans. Relying on natural mortality, we performed oxytocin and arginine vasopressin 1a receptor (OXTR; AVPR1a) autoradiography on 12 *Eulemur* brains (4 MO; 8 NM), representing seven species, to characterize OXTR/AVPR1a distributions across species and compare variation in receptor distributions as a function of mating system. Consistent with the 'intermediary' phylogenetic placement of strepsirrhines, some OXTR/AVPR1a binding patterns were reminiscent of olfactory-guided rodents and others were congruent with more visually oriented haplorhines. By mating system, several nuclei showed differential receptor expression, potentially consistent with a role for both neuropeptides in monogamy, but most areas previously identified as part of a rodent 'pair-bonding circuit' did not exhibit comparable differential receptor expression in *Eulemur*. Circuits identified as key to pair-bonding in rodents cannot be directly invoked to explain pair-bonding in primates. Mapping neurocircuitry in non-model species informs evolutionary mechanisms and neurobiological bases underlying diversity in primate social systems, and studies in nonhuman primates may serve as a valuable bridge for translating findings in rodents to human biology and sociality. Funded by NSF.

41-9 Sharpe, SL; Kansas State University; *sharpes@ksu.edu*
Developing LGBTQIA+ inclusive biology content and classrooms
Oversimplified understandings of biological sex and gender are often deployed both in STEM classrooms and as a political tool to invalidate the existence of queer, transgender, and intersex individuals. This rhetoric discourages LGBTQIA+ students from continuing in these fields, reaffirms harmful misconceptions about human sex, gender, and sexuality in both these students and their heterosexual, cisgender peers, and neglects the true and extraordinary diversity of life on earth. As scientists, educators, and communicators, we have the opportunity to increase the inclusivity of our research, classrooms, and curricula by exploring the social role of biology that has shaped who gets to practice, benefit from, and access it. Although biology education is often presented as value-neutral and divorced from culture, without understanding how eugenics and white supremacy have influenced historical understandings of biological sex, we cannot effectively challenge the biased and binary misunderstandings of human

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diversity that developed as a result and remain widespread. By incorporating and exploring the diversity and complexity of sex, gender, and sexuality in human biology and across taxa, we can instill in our students and audiences an understanding that biology can serve as a source of empowerment for, rather than invalidation of, queer, transgender, and intersex individuals. Such efforts can play a crucial role in increasing retention of LGBTQIA+ students in the sciences and encourage innovative research and science communication exploring sex, gender, and sexuality across taxa.

S7-3 Shavit, K; Yallapragada, VJ; Weiner , S; Oron, D; Sagi, A; Addadi, L; Palmer, B*; Ben-Gurion University, Chemistry, Israel, Weizmann Institute, Physics of Complex Systems, Israel, Weizmann Institute, Structural Biology, Israel, Ben-Gurion University, Life Sciences, Israel, Weizmann Institute, Structural Biology, Israel; *benjamin.palmer61@gmail.com*

Organic crystals in animal coloration and vision

Highly reflective organic crystals are widely used in animal coloration and vision [1]. Guanine crystals, for example, have been studied for over 100 years and their role in structural coloration is well-established. We discuss the less-studied pteridine molecules which are used, in crystalline form, as colorants and as reflectors in vision. Isoxanthopterin crystals form reflectors in the eyes of decapod crustaceans which are used in image-formation, enhancing photon-capture and camouflage [2]. The isoxanthopterin crystals are arranged in nanoparticles, constructed from a shell of isoxanthopterin crystal plates arranged in concentric lamellae around an aqueous core. The reflectors are formed from dense assemblies of nanoparticles. Isoxanthopterin crystals are characterized by layers of planer H-bonded molecules, and the reflectivity of the material derives from the extreme refractive index (n=1.96) parallel to these layers. The reflectivity and scattering of the particles are enhanced by the alignment of the crystals and an optimized core-shell ratio [3]. We also present recent insights on the formation of biogenic crystals from studies of developing organisms. [1] B. A. Palmer, D. Gur, S. Weiner, L. Addadi, D. Oron, Adv. Mater., 30, 1800006 (2018). [2] B.A. Palmer, A. Hirsch, V. Brumfeld, E.D. Aflalo, I. Pinkas, A. Sagi, S. Rozenne, D. Oron, L. Leiserowitz, L. Kronik, S. Weiner and L.

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78-2 Shaykevich, DA*; Pašukonis, A; O'Connell, LA; Stanford University; *shaykeda@stanford.edu*

Homing behavior in native range Rhinella marina

All animals use and navigate space in order to complete vital tasks, such as foraging, mating, and providing care for young. While less studied than some other classes of organisms, many amphibians exhibit sophisticated use of space. The cane toad, *Rhinella marina*, is a bufonid species commonly found throughout Central and South America, but has gained notoriety as a human introduced invader in Australia. There has been considerable attention to the spatial dynamics of invasive toads, but little is known about the behaviors and navigational abilities of native *R. marina*. To test toad ability to return to a home site after being displaced, we performed translocation-homing experiments in the field. Toads were tagged and tracked with radio transmitters to determine baseline movements, showing a general fidelity to specific sites with relatively large movements happening during mating events. Toads were then translocated from their home sites and tracked as they returned home; the toads showed successful navigation following 500 and 1000 meter translocations. Such homing behavior is especially interesting as toads are technically not territorial. Further analysis is needed to understand the true scale of space use and potential navigation abilities in cane toads. Precise homing behavior in a species also paves the way for combining field navigation studies with neuroscience imaging techniques to characterize brain activity associated with homing.

BSP-3-1 Shidemantle, G*; Buss, N; Hua, J; Binghamton University; *gshidem1@binghamton.edu*

Are glucocorticoids good indicators of condition across populations that vary in pollutant tolerance?

Glucocorticoids (CORT) are frequently used in conservation as indicators of stress in wildlife. However, the context-dependent

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nature of CORT means that CORT levels may not always accurately reflect condition. For example, there is growing evidence that populations can evolve or acclimate to human-induced environmental change (i.e. pollutants) by expressing higher tolerance levels. Mechanisms that allow for populations to achieve higher pollutant tolerance may affect CORT and thereby its viability as an indicator of condition. To date, no studies have considered this context. We ask 1) do populations that differ in tolerance to pollutants differentially express baseline and stress-induced CORT and 2) is CORT a viable indicator of condition across populations that differ in tolerance to pollutants? Towards this goal, we identified 3-NaCl tolerant and 3-NaCl susceptible populations of wood frogs. We reared larvae from these populations to metamorphosis in either an environmentally relevant concentration of NaCl or a control. At metamorphosis we used a non-invasive waterborne assay to measure baseline and stress-induced CORT release rate and measured fitness metrics. Regardless of the rearing environment, tolerant populations had lower baseline CORT release rates and responded to an acute stressor by mounting a positive CORT response. In contrast, susceptible populations had higher baseline CORT release rates and decreased CORT in response to an acute stressor. Thus, while CORT levels differ across populations that vary in relative pollutant tolerance, the CORT-fitness relationship across populations was consistent with the CORT-Fitness hypothesis. Collectively, this underscores the utility of CORT as a tool for evaluating wildlife condition that is robust to shifts in population traits.

29-7 Shipman, BM*; Ernst, DA; Dijkstra, JA; Westerman, EL; University of Arkansas, Fayetteville and University of Texas at Dallas, Richardson, University of Arkansas, Fayetteville, University of New Hampshire, Durham; *braden.shipman@utdallas.edu*

Differential gene expression in an invasive ascidian as a response to temperature

Native oceanic biodiversity is under threat worldwide due primarily to anthropogenic factors such as rising ocean temperatures and the introduction of non-native invasive species. One area which continues to be impacted by these threats is the Gulf of Maine, a region which is warming far more rapidly than most oceanic areas.

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This marine community is also threatened by invasive species such as *Botrylloides violaceus*, a colonial ascidian that has colonized large parts of the eastern coastline of the United States. To better understand the mechanisms behind this colonization, we investigated habitat associated changes in gene expression which might underlie this species' ability to adapt to non-native climates. We extracted RNA from colonies of *B. violaceus* from two locations: Nubble Point, ME, a near shore environment, and Isles of Shoals, NH, an offshore environment, collecting three colonies of *B. violaceus* from above and below the thermocline at each site. By comparing gene expression profiles across site and depth, we have identified a host of candidate genes which may be integral in this species' successful adaptation to multiple habitats, including genes involved with stress response such as universal stress protein *A-like* and *META2*, genes associated with osmoregulation, including calcium and sodium transport proteins, and thermoregulation genes such as *HSP30*, *HSPA12A*, and *HSPB6*. These results suggest the acclimatization of *B. violaceus* to non-native climates may be associated with environmentally induced variation in gene expression and provide new directions for future research into the molecular mechanisms underlying the spread of invasive species.

18-6 Shishkov, O*; Nave, GK; Peleg, O; University of Colorado Boulder; *olga.shishkov@colorado.edu*

Internal structure of honey bee swarms

Thousands of swarming honey bees (*Apis mellifera*) hang from a tree branch for hours while scout bees search for a new hive. This is a dangerous time in the life of a bee colony: the bees are exposed to weather and predators, and if the queen does not survive, neither will the colony. The bees form large clusters consisting entirely of bees hanging from each other, surrounding the queen. We investigate how bees arrange themselves within a swarm by probing swarms of 5,000 to 10,000 bees with x-ray computed tomography. The swarm hangs from a flat circular board to which the queen is attached, preventing the swarm from leaving. We find that the density of bees is highest closest to the attachment surface, where bees arrange themselves in layers for stability. The density of bees decreases towards the tip of the swarm. We track individual

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bees within the swarm to find evidence of division of labor between the bees. Most bees are arranged in nearly immobile structures, and the remainder of the bees are free to roam within the less dense areas of the swarm. Thus, a honey bee swarm self-organizes into a living structure that distributes loads among the bees, maintains structural stability, and responds to external stimuli.

7-8 Shitikov, AD*; Voronezhskaya, EE; Melnikova, VI; Moscow State University, Koltsov Institute of Developmental Biology RAS; *alexandr.sh98@gmail.com*

Serotonylated proteins in spermatozoa flagellum: detection and the possible impact on gametes motility in mammals

The reproductive success drastically depends upon gametes' motility. In the case of mammals, the character and speed of spermatozoa movements are determined by flagellum structure and activity. Modifications of structural flagellar proteins, for example, microtubule α-tubulin acetylation, strongly affect stabilization, softening, and flexibility of flagella. The possible impact of other posttranscriptional modifications is less clear. Here we demonstrate the presence of serotonylated proteins (covalent binding of serotonin catalyzed by enzyme transglutaminase) in rodents' testis and spermatozoa. We combined a modified click-reaction method with propargylated serotonin (5-PT) and azide-biotin or azide-Alexa488 with immunostaining and 3D confocal imaging and performed detailed visualization during rat and mice spermatogenesis. Serotonylated proteins are located in a zone of late spermatids within the testis and in the acrosome and the proximal part of the flagellum of mature isolated spermatozoa. The positive reaction occurs in the same regions after 5-PT click-reaction, immunostaining with anti-5-HT, and anti-N-e(γ-glutamyl) lysine antibodies. Cystamine (transglutaminase inhibitor) decreases the staining signal intensities confirming the transglutaminase-dependent specificity of all labeling. Several flagellar structural proteins demonstrate a high degree of colocalization with 5-PT and anti-5-HT labeling suggesting them as candidate targets for serotonylation. Our finding of serotonylated proteins in specific zones of the mammalian testis and within mature spermatozoa suggested their role in spermatozoa capacitation and mature

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spermatozoa motility. The work was supported by Russian Science Foundation # 17-14-01353.

13-4 Shoele, K*; Murphy, D; Florida State University, University of South Florida; *kshoele@fsu.edu*

Swimming with many legs: Hydrodynamics and scaling of metachronal rowing

Metachronal rowing is a swimming technique used by many ecologically and environmentally important aquatic organisms such as shrimp and krill. Metachronal rowers sequentially stroke multiple bristled swimming legs or paddles in a back-to-front sequence in order to swim. The hydrodynamic interaction between paddling legs is regulated for different locomotion tasks such as hovering or forward motion. Moreover, the change in the shape of the leg and their porosity can play an important role in synergistic flow interactions among the paddles. This mode of swimming in nature spans the greatest range of Re up to 5 orders of magnitude. Here, we present our computational and theoretical work compared with previous experiments to understand the role of paddle geometry and kinematics and find why certain design elements are common among successful metachronal rowers. The final discussion will be provided regarding the presence of an overarching scaling relationship for metachronal rowing based on selective nondimensional characteristic numbers that can capture the underlying flow physics of the metachronal rowing modes.

S12-8 Shogren, EH*; Boyle, WA; University of Rochester, Kansas State University; *elsie.shogren@gmail.com*

Dancing in the rain: environmental drivers of behavioral and social variability in White-ruffed Manakin courtship displays

Tropical animals respond to rainfall in population-specific ways. In extremely wet regions, endotherms experience heavy rains as stressors with consequences for behavior and demography. Ultimately, such stressors can affect the relative strength of abiotic selection, reducing the scope for sexual selection and other sources of biotic selection. We studied population-level differences in the response to biogeographic gradients of rainfall in White-ruffed Manakins (*Corapipo altera*) on the Caribbean slope

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of Costa Rica, a species having a lek mating system subject to strong sexual selection. Previously, we documented behavior in a population inhabiting an extremely wet location where estimates of apparent survival were low and the turnover of display sites and dominant, displaying males was high and positively associated with local rainfall. Males also frequently engaged in coordinated display, and sub-adult males practiced in the presence of adults. Over three breeding seasons (2017-2019), we studied the same species and metrics in a population located only 110 km away, but in a location receiving roughly half as much rain. We tested behavioral predictions of four alternative mechanisms linking rainfall to reproductive behavior. Using data derived from 1350 hr of observations at 40 display logs, we found fewer sub-adult males practicing at display sites and coordinated adult male displays were less frequent. Multiple mechanisms potentially underlie links between rain and the population-specific differences we documented. Our results are consistent with rain constituting an important source of abiotic selection for tropical endotherms and modulating the scope for sexual selection near the extremes of a species' hygric niche.

97-14 Shrimpton , SJ*; Streicher , JW; Gower, DJ; Bell, RC; Fujita, MK; Schott, RK; Thomas, KN; The Natural History Museum, London; University College London, London, The Natural History Museum, London, California Academy of Sciences, San Francisco, CA; National Museum of Natural History, Smithsonian Institution, Washington DC, The University of Texas at Arlington, TX, York University, Toronto; National Museum of Natural History, Smithsonian Institution, Washington DC; *samuel.shrimpton.18@alumni.ucl.ac.uk*

Eye-body allometry across biphasic ontogeny in anuran amphibians

Many frogs and toads (Amphibia: Anura) exhibit biphasic lifecycles, inhabiting different visual environments across ontogeny (e.g. aquatic to terrestrial). Ecological differences influence eye size across species, however, these relationships have not yet been explored across life stages in a developmental allometric context. To explore the effects of different tadpole and adult ecologies on eye-body scaling, we sampled developmental series from twelve anuran species. Of these, six species exhibited a significant change in allometric slope between tadpoles and adults. Species

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with benthic larvae had significantly higher slopes as tadpoles (but not as adults) than species with nektonic larvae, indicating increased relative eye growth during their aquatic life stage. We also found higher slopes in tadpoles of species with high eye investments as adults, which may relate to preparation for post-metamorphic ecologies where vision is important. Our study suggests that relative eye growth in the initial and later stages of biphasic anuran ontogenies is somewhat decoupled, and is shaped by the ecological needs of both tadpoles and adults.

S5-4 Siddall, R; Ibanez, V; Byrnes, G; Full, RJ; Jusufi, A*; Max Planck Institute for Intelligent Systems, UZH and MPI for Intelligent Systems, Siena College, Univ. of California, Berkeley; *ardian@is.mpg.de*

Tail responses facilitate lizard reorientation during directed aerial maneuverability

Arboreal animals face numerous challenges when negotiating complex three dimensional terrain. Directed aerial descent and gliding flight allows for rapid traversal of arboreal environments, but presents control challenges. Some animals, such as birds or gliding squirrels, have specialized structures to modulate aerodynamic forces while airborne. However, many arboreal animals do not possess these specializations but still control posture and orientation in mid-air. One of the largest inertial segments in lizards is their tail. Inertial reorientation can be used to attain postures appropriate for controlled aerial descent. Here we discuss the role of tail inertia in a range of mid-air reorientation behaviors using experimental data from geckos in combination with general mathematic and physical models. Geckos can self-right in mid-air by tail rotation alone. Equilibrium glide behavior of geckos in a vertical wind tunnel show that they can steer towards a landing surface using rapid, circular tail rotations to control pitch and yaw. Multiple coordinated tail responses are required for the most effective terminal velocity gliding. A mathematical model allows us to explore the relationship between morphology and the capacity for inertial reorientation by conducting sensitivity analyses. Physical models further define the limits of performance and generate new control hypotheses. Such comparative analysis allows predictions about the diversity of performance across a

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range of lizard morphologies and provides insights into the evolution of aerial behaviors.

61-13 Sidlauskas, BL*; Botero, C; Burleigh, JG; Hazkani-Covo, E; McGuire, J; Meachen, J; O'Meara, BC; Roberts, T; McClain, C; Oregon State University, Corvallis, OR, Washington University in Saint Louis, St. Louis, MO, University of Florida, Gainesville, FL, The Open University of Israel, Ra'anana, Israel, Georgia Institute of Technology, Atlanta, GA , Des Moines University, Des Moines, IA, University of Tennessee, Knoxville, TN, Natural History Museum of Los Angeles County, Los Angeles, CA, Louisiana Universities Marine Consortium, Chauvin, LA; *brian.sidlauskas@oregonstate.edu*

George Gilchrist's sage advice on everything a new scholar should know

Between 2008 and 2010, George Gilchrist served as a sabbatical fellow and periodic visiting scholar at the National Evolutionary Synthesis Center (NESCent). In addition to researching the evolution of performance curves in seasonal environments, he enthusiastically dedicated his time at NESCent to mentoring the resident postdoctoral fellows and other members of that academic community. Notably, he worked with faculty at diverse institutions to assemble a document passing along knowledge and advice about everything a new professor or professional scholar should know. That document includes wisdom garnered from his own career and insights from his network of colleagues, all of whom were leaders in the field of evolutionary biology. George's recent passing (1954-2020) sparked us to revisit his sage advice and reflect on how his influence has shaped our successes, now that we have reached the midpoints of our careers. We summarize his recommendations, reflect on which pieces were most helpful, and update the advice to address changes in the academic landscape over the last decade. In so doing, we hope that a new generation of scholars can benefit from George's wisdom, much as we did.

BSP-6-8 Simonitis, LE*; Gahn, MB; Kaiser, K; Plön, S; McLellan, WA; Marshall, CD; Texas A&M University at Galveston, Texas A&M University at Galveston, Texas A&M University, Bayworld Centre for Research and Education (BCRE), Port Elizabeth, South Africa,

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University of North Carolina Wilmington, Texas A&M University at Galveston, Texas A&M University; *laureneve@live.com*

A tale of three inks: Comparison of free amino acid composition of ink from california sea hares, common cuttlefish, and pygmy sperm whales

Inking is a chemical defense mechanism which has evolved independently in disparate taxa. This study investigated the L- and D-amino acid composition of ink collected from the in vivo secretions of California sea hares (*Aplysia californica*), the ink sacs of common cuttlefish (*Sepia officinalis*) and the colon of pygmy sperm whales (*Kogia breviceps*). Free amino acids were analyzed by high performance liquid chromatography and fluorometric detection. Ink was prepared for analysis through two methods: traditional filtration through a 0.2 µm nylon filter (VWR) and a new centrifugation method which yielded a higher recovery of amino acids. There was no single or cluster of amino acids which was consistently elevated across the three different inks. The most abundant amino acids were D- and L-alanine in *Kogia* ink, L-alanine and L-valine in Cuttlefish ink, and L-serine and L-glycine in *Aplysia* ink. We were able to explain between 1% to 20% of the inks' dissolved organic carbon (DOC). Due to previous ink composition studies from various taxa, we specifically looked for both free dopamine and L-DOPA but, we did not observe the presence of either compound in any of our ink samples. Instead, we found two unknown fluorescent peaks with similar retention times that may have misidentified as L-Dopa and dopamine in previous studies. The presence of D-amino acids, typically found in the cell walls of bacteria, provides evidence that ink arose within digestive systems or other excretory pathways.

9-8 Sinnott-Armstrong, MA*; Smith, SD; Vignolini, S; University of Colorado-Boulder and University of Cambridge, UK, University of Colorado-Boulder, University of Cambridge; *msinnottarmstrong@gmail.com*

Lantana camara also uses lipids to make metallic blue fruit: a second origin of lipid-based structural color

The most distinctive colors in nature are produced not by pigments (such as anthocyanins or carotenoids) but rather by an alternative mechanism, structural color. Structural colors are extremely rare

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in plants, and only a handful of species have been described as having structural colors in their fruits. Two photonic structures have been described thus far from fruits and seeds: helicoidal cellulose nanofibers producing polarized light reflectance (known from two origins, in *Pollia condensata* and *Margaritaria nobilis*), and a recently described lipid-based disordered multilayer reflector in *Viburnum tinus*. Here, we report convergent evolution of this lipidic multilayer reflector in the fruits of a second species, the commonly planted and highly invasive shrub *Lantana camara* (the common lantana). Using transmission electron microscopy and serial EM tomography, we describe the developmental trajectory of this photonic structure during fruit maturation, and discuss how this lipid-based structure assembles over time from individual lipid droplets to forming a plate-like structure. We compare our findings in *Lantana camara* to the similar structure described in *Viburnum tinus* and discuss broader implications for fruit color evolution and the ecological consequences of distinctive fruit coloration.

71-1 Sivitilli, DM*; Weertman, WL; Busch, EL; Ullmann, JF; Smith, JR; Gire, DH; University of Washington, Alaska Pacific University, Yale University; *domsivi@uw.edu*

Strategies of single arm foraging in Octopus rubescens in the absence of visual feedback

Octopuses control their multiple, soft limbs with the aid of sophisticated peripheral neural circuitry within their arms and suckers. The octopus is largely dependent on this peripheral nervous system and the information acquired by their densely innervated suckers to navigate and forage. Characterizing how these local neural circuits locally generate adaptive behavior within soft limbs provides an approach for the development of technologies involving soft robotics, distributed computing, and neuroprosthetics. Octopuses commonly forage at night and reach their arms into visually occluded spaces while searching for prey. To characterize the octopus' ability to forage using only the local chemotactile systems within its arms, we investigated the strategies the Pacific red octopus (*Octopus rubescens*) uses to find food using a single arm within a visually occluded environment. We developed these environments using computer-aided design and they

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were 3D printed for experimental use. We trained octopuses to use a single arm to explore these 3D printed environments for a food reward. By varying the location of the food item within these environments and tracking the arm using DeepLabCut markerless pose estimation software, we characterized movement patterns used by the arm as it foraged. We used a simplified compartmental model of the arm to evaluate control algorithms that could support these movement patterns. Our results suggest that, absent visual guidance, the octopus relies on a collision-based arm control strategy that emerges from mechanisms of sucker coordination to simplify the control of its soft, highly flexible limbs.

107-10 Skelton, ZR*; Wegner, NC; Prinzing, TS; Hastings, PA; Scripps Institution of Oceanography, University of California San Diego, Southwest Fisheries Science Center, National Oceanic and Atmospheric Administration , Earth to Oceans Research Group, Simon Frasier University; *zskelton@ucsd.edu*

Comparison of temperature preference and metabolic thermal sensitivity between two juvenile coastal shark species

Sharks behaviorally thermoregulate in order to optimize physiological processes. Juvenile sharks often utilize estuaries, which can provide warm water temperatures that increase metabolism and facilitate growth. Both the California Horn Shark (*Heterodontus francisci*) and the Leopard Shark (*Triakis semifasciata*) occupy estuaries as juveniles and represent contrasting activity levels; horn sharks are relatively sedentary while leopard sharks are more active and mobile. The aim of this study was to better understand the relationship between behavioral thermoregulation and metabolism in response to temperature in these two species. Our objectives were threefold: 1) identify the temperatures juveniles prefer, 2) assess the sensitivity of metabolism (Q_{10}) to temperature via measurements of oxygen consumption, and 3) compare these results across species, sex, and seasonal acclimation treatments. Using a shuttlebox system, our results show that juvenile horn sharks and leopard sharks have comparable thermal preferences and temperature ranges. While leopard sharks exhibited higher metabolic rates than horn sharks across all temperatures, horn sharks exhibited a higher relative overall Q_{10} suggesting their metabolism has greater thermal dependence. There was no effect of seasonal temperature acclimation

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on any of our tested parameters. Compared to leopard sharks, horn sharks likely target stable-temperature environments closer to their preferred temperature. This work highlights the importance of temperature-induced physiological and behavioral responses in understanding habitat use during vulnerable life stages.

14-4 Slibeck, B*; Law, CJ; Columbia University, American Museum of Natural History; *cjlaw9@gmail.com*

Ecological drivers of carnivoran body shape evolution

Morphological diversity is often attributed to adaptations to distinct ecological traits. Although biologists have long hypothesized that distinct ecologies drive the evolution of body shape, these relationships are rarely tested across macroevolutionary scales. Here, I examined if locomotor, hunting, and dietary ecologies influenced body shape evolution in carnivorans, a morphologically and ecologically diverse clade of mammals. I found that neither of these ecological factors influenced the evolution of carnivoran body shape and the underlying morphological components that contribute to body shape variation. Instead, the evolution of carnivoran body shape is largely influenced by phylogenetic history, as evolutionary shifts primarily occurred along taxonomically named clade branches. Similar to body size, body shape is a prominent feature of vertebrate morphology that may conceal one-to-one mapping relationships of organismal morphology onto ecological function across macroevolutionary scales. Overall, the results demonstrate that morphological evolution and ecological diversity can be largely decoupled across macroevolutionary scales.

101-5 Slibeck, BB; Columbia University; *bbs2133@columbia.edu*

What drives range size variation: Effects of morphology on range size in the Musteloidea

Understanding the driving forces behind variation in range size is crucial to conservation efforts in a world where habitats are rapidly changing and becoming increasingly fragmented due to human intervention. To better understand variation in species range sizes, we must identify the behavioral, morphological, and ecological characteristics that influence it. Doing so will shed

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light on the causes of variation in geographic distribution, and thus, chances of species survival. Here, we tested the effects of ecology, morphology, and social behaviors on range size. We used the carnivoran superfamily Musteloidea (which includes badgers, otters, raccoons, weasels, and red pandas) as our model clade because of its nearly global distribution and large variance in body shapes, lifestyles, and social behaviors. We predicted that body mass, diet type, and social behavior would influence range area. Contrary to our prediction, the phylogenetic ANOVA revealed that body mass, social grouping, diet type, head to body elongation ratio, and cranial size did not have a significant effect on species range, with habitat type revealing significant differences only between marine and terrestrial aquatic species, and cranial shape exhibiting a weak correlation. These results reaffirm the complexity of species range, and suggests that within this group, no single metric is able to explain the large variation in species distribution. However, the presence of a significant relationship between at least one axis of cranial morphometric variation and species range suggests a relationship between jaw geometry and adaptability potentially as a result of increased jaw musculature and thus greater bite force. Furthermore, we suggest directions for future study through the examination of the effects of locomotion, sexual dimorphism, and individual territorial ranges on species range size.

64-8 Smail, SJ; Stuart, V; Zimmerman, LM*; Millikin University; *lmzimmerman@millikin.edu*

Relationships between thermal preference, parasites, and antibodies in the red-eared slider turtle

Because they are ectothermic, immune function in reptiles is affected by temperature. The physiology and transmission of parasites can also be influenced by temperature. In red-eared slider turtles (*Trachemys scripta*), previous studies have separately examined the effect of temperature on B cell function *in vivo* and the correlation between antibody levels and parasite prevalence. This study aimed to examine the interaction of thermal preference of the sliders, antibodies, and intestinal parasites in an individual. Plasma and mucosal samples were collected and will be used to measure total antibody levels. Fecal samples were

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collected and the presence of intestinal parasites was determined. Thermal preference was determined by placing a turtle into a box with a heat gradient for three hours. Temperature was recorded every minute using a Thermochron iButton recording device attached to the carapace. Maximum temperature (Tmax), average temperature (Tavg), and minimal temperature (Tmin) were determined for the last hour. Tmin was higher in turtles with intestinal parasites. Tmax and Tavg were not significantly higher in turtles with intestinal parasites. Females had significantly higher Tmax and Tavg (but not Tmin) than males. The higher minimum temperature of turtles with parasites may be a behavioral fever to aid in immune activation and promote the ability to clear the parasites. Alternatively, a higher temperature may lead the turtles to be more active and thus the turtles may be exposed to more parasites.

93-8 Smedley, GD*; McElroy, KE; Serb, JM; Iowa State University, Ames, IA; *gdsmedley13@gmail.com*

Distinguishing between additive and epigenetic effects in light absorbance of mutant retinochromes

The relationship between genotype and phenotype is nontrivial due to often complex molecular pathways that make it difficult to unambiguously relate phenotypes to specific genotypes. Photopigments present an opportunity to directly relate the amino acid sequence to the phenotype in the form of the absorbance peak or λmax. We examined the relationship of genotype and phenotype of the invertebrate non-visual opsin retinochrome by conducting reciprocal mutagenesis experiments between the common bay scallop, *Argopecten irradians, and the closely related king scallop, Pecten maximus. We identified three amino acid sites of likely functional importance, expressed site-directed mutants in-vitro, and spectrally characterized the resulting phenotype of each mutant photopigment. Our results show that the mutation of amino acids lining the binding pocket of retinochrome can change peak absorbance and may be important for fine spectral tuning; however, residue changes were not always additive in the mutant phenotype. We observed most mutations causing a blue shift in absorbance, with shifts ranging from a 12nm blue shift to 5nm red shift from the wild-type retinochromes. These findings highlight the spectral tuning effect of amino acids away from the Schiff-base linkage site*

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and the counter-ion, and suggest that secondary sites may be responsible for intramolecular epistasis. This work highlights the potential importance of binding pocket shape in the evolution of spectral tuning and builds on our ability to relate genotypic changes to phenotypes in an emerging model for opsin functional analysis.

53-3 Smeds, EA*; Dahlhoff, EP; Rank, NE; Sonoma State University, Rohnert Park, CA, Santa Clara University, CA; *smeds@sonoma.edu*
The genomic basis of local thermal adaptation in a montane insect
Adaptation to prevailing thermal conditions is crucial to the survival of any organism. Temperature dictates the stability and conformation of biomolecules, and populations must ensure that the structure of their enzymes is properly tuned to environmental temperatures. Populations that exist across habitats which differ chiefly by temperature are expected to show patterns of local adaptation, whereby the highest level of genetic differentiation is found at loci involved in thermal adaptation. However, detecting genetic loci associated with thermal response in wild populations is often hampered by the confounding effects of phenotypic plasticity. We collected hatchling larvae of a montane leaf beetle, *Chrysomela aeneicollis*, from equal-elevation sites in three isolated drainages along a north-south latitudinal gradient California's Sierra Nevada, and raised them to third instar in the laboratory under common garden conditions. Larval running speed was measured before and after a 36°C heat treatment, and whole genome data was obtained from 206 larvae using Illumina paired end sequencing. We performed an FST outlier test to identify single-nucleotide polymorphisms with the highest level of differentiation between the three populations, as well as an association analysis to identify SNPs associated with running speed following heat treatment. We found that native drainage did not significantly affect larval running speed, which indicates that the common garden design successfully controlled for phenotypic plasticity. This experiment provides insights into how genomic variation allows organisms living at the edge of their thermal tolerance to adapt to changing conditions.

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14-3 Smith, HF*; Adrian, B; Koshy, R; Alwiel, R; Wright, W; Grossman, A; Midwestern University, Glendale, AZ; *hsmith@midwestern.edu*

Adaptations to cursoriality and digit reduction in the forelimb and hind limb musculature of the African wild dog (Lycaon pictus)

The African wild dog, *Lycaon pictus*, is native to southern and eastern Africa, and is unique among canids in its purported tetradactyly, nomadic lifestyle, and distinct reliance on exhaustive predation. This cursorial behavior and lack of a fully formed digit I presumably alter the structure, position, and functions of limb musculature. We conducted dissections and quantitative data collection of forelimb and hind limb myology of *L. pictus*, including descriptions, photographs, muscle maps and quantitative analyses. In *L. pictus* , muscles involved in forelimb posture and stability, and those that store elastic energy, have enlarged bony attachments. It has smaller wrist rotators than other carnivorans, likely to increase antebrachial stability over rotatory movement. While a full developed digit I is absent, we discovered a vestigial metacarpal I, resulting in changes to pollical muscle insertions, which may help stabilize the carpus during long distance locomotion and provide proprioception. In the hind limb, quadriceps femoris muscles were separated, which may allow a functional decoupling of hip flexor and stifle extensor components of thigh musculature, such that tensor fascia latae + rectus femoris flex the hip while the vasti extend the stifle to facilitate energy conservation during prolonged locomotion. Crural musculature was heavily invested in fascia and an extra gracilis tendon was present. Reductions and altered attachments of tibialis and fibularis muscles suggest reduced leverage during inversion/eversion and greater emphasis on stability of talocrural joint.

2-3 Smith, CH*; Pfeiffer, JM; Johnson, NA; University of Texas, Austin, TX, National Museum of Natural History, Smithsonian Institution, Washington, DC, U.S. Geological Survey, Wetland and Aquatic Research Center, Gainesville, FL; *chase.smith@austin.utexas.edu*

Comparative phylogenomics reveal complex evolution of life history

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strategies in a clade of bivalves with parasitic larvae (Bivalvia: Unionoida: Ambleminae)

Freshwater mussels (Bivalvia: Unionoida) are a species-rich group with biodiversity patterns strongly shaped by a life history strategy that includes an obligate parasitic larval stage. The subfamily Ambleminae represents the most diverse in Unionoida with over 340 species. Many amblemines have evolved specialized patterns of host use, which are associated with equally specialized host infection strategies. Using robust phylogenomic methods, we set out to reconstruct the evolution of life history traits in a clade of amblemines that have a suite of characters ostensibly adapted to infecting its molluscivorous host. Anchored hybrid enrichment and ancestral character reconstruction revealed a complex pattern of life history evolution with host switching and multiple instances of convergence, including reduction in size of larvae, increased fecundity, and growth during encapsulation. Our phylogenomic analyses also recovered non-monophyly of taxa exhibiting multiple traits used as the basis for previous taxonomic hypotheses. Taxa with axe-head shaped glochidia were resolved as paraphyletic, but our results strongly suggest the complex morphology is an adaptation to reduce larval size, with reduction in size further accentuated in taxa previously assigned to *Leptodea*. To more accurately reflect the evolutionary history of this group, we make multiple systematic changes, including the description of a new genus, *Atlanticoncha* **gen. nov.**, and the synonymy of *Leptodea* under *Potamilus*. Our findings contribute to the growing body of literature showing that cladistic hypotheses based solely on morphological characters, including larval morphology, can be flawed in freshwater mussels.

S8-8 Smith, AM; Ithaca College; *asmith@ithaca.edu*

Adhesion with tough gels: inspiration from the sticky defensive secretions of dusky slugs

Tough gels have great potential as medical adhesives. Their deformability makes them much more compatible with soft tissues than solid adhesives. While many gels are better suited as lubricants, recent work has characterized gel-toughening mechanisms that can lead to markedly different mechanics. The dusky slug *Arion subfuscus* takes advantage of such a mechanism to produce an

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extraordinary defensive secretion. It exudes from the animal's back and adheres strongly to whatever touches it, rapidly setting into a tough glue. The glue has several highly desirable properties: 1) it adheres to a wide variety of surfaces despite the presence of water, 2) it sets rapidly, changing from a viscous exudate into a firm gel within seconds, and 3) it is unusually tough. Recent work has clarified how it gains these properties. A group of highly abundant proteins that are unique to the glue adhere to different surfaces. These proteins are ligand-binding proteins related to lectins, and likely oligomerize to present multiple binding domains that can join the glue components to the surface. These glue components set rapidly via an oxidation reaction leading to stable cross-links within a protein network. Finally, the combination of a polysaccharide and a protein network creates a double network that acts synergistically to provide toughness. The polysaccharides are folded and easily extensible, but the interpenetrating proteins are extensively cross-linked to provide stiffness. The cross-links act as sacrificial bonds, dissipating energy as they fail. This requires a great deal of energy because the polysaccharides ensure that the glue deforms extensively before failure. The structural features that provide adhesiveness, rapid setting, and toughness provide an intriguing blueprint from which to design novel medical adhesives.

14-5 Smith, HF*; Townsend, KE; Adrian, B; Marsh, S; Levy, S; Hassur, R; Nagy, S; Mohamed, H; Echols, S; Grossman, A; Midwestern University, Anatomy; *hsmith@midwestern.edu*

Functional adaptations in the forelimb and hind limb morphology of the snow leopard (Panthera uncia)

The snow leopard (Panthera uncia) is anatomically and physiologically adapted for life in the rocky terrain of alpine zones in Central and South Asia. P. uncia is scansorial, and typically hunts solitarily using overhead ambush of prey, rather than the typical stalking pattern of other large pantherines. In this study, we dissected, documented in detail, and imaged the limb anatomy in two adult P. uncia specimens (1M/1F). We found notable, functional differences in P. uncia limb morphology compared to other carnivorans. Enlarged scapular and pectoral musculature likely provide extra forelimb power and stability for climbing

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steep, icy, mountainous terrain. An unarticulated bony clavicle, greatly reduced compared to other pantherines, may provide greater flexibility to the pectoral girdle. Extra muscular heads and insertions around the elbow provide stability and power to the joint. Intrinsic muscles of the palmar manus are broad and fleshy, creating an enlarged surface area to evenly distribute body weight while walking on soft snow. Tendinous connections between the plantar digital flexors and extensors in the pes may coordinate fine pedal movements. Expanded hip adductors and extensors likely facilitate climbing and head-first descent down cliffs. The attachment sites of several key stifle flexors suggest an increased need for propulsion during running and leaping. Enlarged plantar flexors facilitate rapid, powerful ankle extension, as is required during jumping. P. uncia displays some adaptive parallels with arboreal climbing pantherines, such as the clouded leopard, while also showing adaptations for terrestrial running.

25-6 Smith, SM*; Angielczyk, KD; Field Museum of Natural History, Negaunee Integrative Research Center; *smsmith@fieldmuseum.org*
Adventures inside shrew vertebrae: trabecular bone morphology and regionalization in Soricidae
The regionalized vertebral column is a hallmark of mammalian morphology and reflects functional differentiation of the vertebral regions. Mammalian vertebrae are serially homologous and morphologically patterened by *Hox* expression, but also vary in number and gross morphology across species. The trabecular bone inside vertebral centra is more plastic than gross vertebral bone, and structurally adapts to better withstand forces it experiences during life. However, the functional regionalization of vertebral trabecular bone is poorly examined. Are there trabecular "regions" reflecting the differing functions and *in-vivo* stress patterns of gross morphological vertebral regions? Or is trabecular morphology homogeneous throughout the spine, suggesting that differences in functional demands are borne exclusively by external characteristics? To address these questions, we collected μCT scans and linear measurements of cervical, thoracic, and lumbar vertebrae in four species of large shrews, including two species of the hero shrew *Scutisorex*, which has a highly modified vertebral column. We compared linear measurements and trabecular bone characteristics of

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the cranial and caudal ends of each centrum across species. To detect unique vertebral regions, we executed principal coordinates analysis and segmented regression on three versions of our data set: trabecular bone data only, external measurements only, and the two combined. We found that some regionalization is recovered using only trabecular bone data, but trabecular bone regions do not correspond exactly to gross vertebral regions. This reflects divergence between the functional signals of internal and external vertebral bone morphology, which should be further examined in a kinematic context.

BSP-11-6 Smith Paredes, D*; Vergara, ME; Stundl, J; Moses, MM; Behringer, RR; Cerny, R; Bhullar, BAS; Yale University, CalTech, University of Texas, Charles University,
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Exploring the evolution of the tetrapod limb musculature by studying its embryology

The pattern of cleavage of the shoulder and arm muscles has been described only in a handful of taxa (urodeles, lizards, turtles, marsupials and birds); although the information from these seminal investigations has been used as a tool for understanding homologies across amniotes, that understanding is limited by restricted taxonomic scope and by the imaging technologies then available. Half a century later, we have new tools for studying and visualizing developing anatomy. We studied the development of closely spaced embryonic series of mammals, archosaurs, lizards and turtles - a sample comprising all major amniote clades - and studied the embryology of forelimb muscles, along with the nerves and skeleton, by using fluorescent immunostaining and confocal microscopy. Our data reveal that muscle division is much more conserved across amniotes than previously described. We tracked and followed the embryonic origin of each adult muscle, comparing it to supposed homologues across clades. Based on our results, we propose a reconsideration of some assumed homologies and provide new information regarding the development and evolution of amniote forelimb musculature. In addition, we compare this developmental pattern with that of amphibians and non-tetrapods, revealing drastically different modes of development at the origin of

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tetrapods and shedding light on the sequence of events in the evolution of paired appendages.

57-10 Snekser, JL*; Ashe, TM; Itzkowitz, M; Canisius College, Buffalo, LIU Post, Brookville, Lehigh University, Bethlehem; *snekser1@canisius.edu*

Effectiveness of Cyprinodon bovinus pupfish territorial defense against Gambusia nobilis egg predation: a tale of two endangered fishes

Recent conservation efforts have shifted to include a more holistic approach to protection of ecosystems as we further recognize the interconnectedness of ecological community members. It is not commonly sufficient to focus on just one endangered species within recovery plans as we usually find multiple species in peril within threatened environments. Here, we continue a long-term effort to understand the complex behavioral dynamics of the Leon Springs pupfish (*Cyprinodon bovinus*) and the Pecos gambusia (*Gambusia nobilis*), both of which are classified as endangered species. The Leon Springs pupfish is critically endangered and only found in one spring system in Western Texas, USA. In addition to substantial habitat loss, these egg-laying, territorial fish may be suffering from small population sizes due to the constant predation of newly laid eggs by the generalist Pecos gambusia. Leon Springs pupfish continuously defend their small territories from invading gambusia, with long and short chases, appearing to attempt to remove the potential egg predators. From video recordings of these endangered fishes within their only natural habitat, we monitored behavioral interactions to determine if these aggressive chases by male pupfish are effective in actually removing gambusia from the territory for a substantial period of time in order to allow for successful egg deposit following spawning. The results found have implications for future recovery plans in our efforts to protect these endangered fishes.

24-1 Snell-Rood, EC*; Smirnoff, D; University of Minnesota; *emilies@umn.edu*

Function' in evolutionary biology and biomimetics: moving past the philosophical conundrum

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'Function' is a key concept in both evolutionary biology and bioinspired design. Distilling a problem to essential functions allows designers to look to evolved traits that perform analogous functions in biological systems. However, 'function' has a fraught philosophical history in evolutionary biology because it often assigns purpose to a trait that goes beyond the evolutionary processes that led to the origin of that trait. Here we review three key sets of ideas from evolutionary and organismal biology that can broaden and clarify biomimetic approaches by more explicitly and carefully considering 'function.' First, mapping a trait of interest within the integrated fitness of an organism can clarify limits to copying a particular adaptation for a human application. Second, detailing the dependency of a trait on other traits, and levels, within an organism can clarify the extent to which a designer must replicate other organismal traits for a given function. Third, some traits may show a derived function as a byproduct of selection (e.g., a spandral), and considering functional byproducts gives clues for where to search for inspiration in human bio-inspired design. We develop a conceptual framework that draws from key concepts in evolutionary and organismal biology to aid engineers and designers in their search for biological inspiration.

66-12 Socha, JJ*; Pulliam, JN; Salcedo, MK; Hernandez, AM; Jackson, BE; Virginia Tech, Harvard University, Longwood University; *jjsocha@vt.edu*

Wing flexibility of cicadas during takeoff: A pandemic story

Coming soon!

8-5 Sockman, KW*; Lyons, SM; Caro, SP; University of North Carolina; *kws@unc.edu*

Immediate effects of song competition on the song of male Lincoln's sparrows

The songs of many songbird species contain trills—rapid repetitions of a single syllable type. Both within and between species, the maximum speed of syllable production (trill rate) is negatively correlated with the trill's frequency bandwidth, presumably due to biomechanical constraints on the vocal tract. Trills that maximize

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trill rate relative to bandwidth are said to be high performance, and, in a mate-choice context, female Lincoln's sparrows (*Melospiza lincolnii*) prefer male songs that are high performance over those that are low performance. Using Lincoln's sparrows, we asked whether the trill performance to which males are exposed can serve as a competitive signal and therefore affect their own song behavior. We manipulated songs by cutting silence from between trill syllables of each recording and pasting it in the corresponding space of the recording's digital copy, thereby making two song-playback treatments-one of low-performance trills and the other of high-performance trills, both within the species' natural variation of trill performance. In a within-subjects design that was balanced by the order of treatment exposure, we exposed free-ranging males to a 6-minute playback of one treatment one morning followed the next morning by the other treatment. We found no effect of treatment level on the trill performance of subjects during the 10 min immediately following playback. However, relative to the low-performance treatment, the high-performance treatment elevated the trill length and song count of subjects and reduced their songs' trill-count, syllable-count, and length. These results show that subtle variation in the trill performance to which a male is briefly exposed can significantly alter his song, consistent with the hypothesis that trill performance can serve as a competitive signal between males.

35-5 Solomon-Lane, TK*; Wallace, KJ; Butler, RM; Hofmann, HA; Pitzer, Scripps, and Claremont McKenna Colleges, University of Texas at Austin, University of Chicago; *tsolomonlane@kecksci.claremont.edu*

Behavioral development and the emergence of adult phenotype in a highly social fish

Development is essential to understanding organismal phenotypes, including adult traits relevant to fitness and health. We studied how social behavior develops in the highly social cichlid fish, *Astatotilapia burtoni* . Focal fish were studied as juveniles (2 months old), through reproductive maturation, until young adulthood (6 months old). For the first 2 months, fish were housed and observed in freely-interacting triads, then tested individually in a battery of four behavior assays: open field exploration,

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social cue investigation, dominance behavior, and subordinate behavior. Fish were then housed in groups of 6 fish for an additional 2 months, after which they were tested individually again using the same battery. Body size was measured throughout the experiment, and gonadosomatic index (GSI) was quantified at the end. We find that overall repeatability of behavior across the four time points was low. However, principal components analysis revealed that the variance structure of all behavior measures remained remarkably stable over time. These results suggest that behavioral phenotypes can vary considerably throughout early life, while at the same time, the overall parameter space any individual can traverse throughout behavioral development may be somewhat invariant. Finally, we investigated the development of traits relevant to adult reproductive success, such as body size, somatic growth, and GSI, using model selection and averaging. Both morphological and behavioral traits, especially submissions, are predictive of young adult phenotype. Together, our results expand our understanding of behavioral development and the origins of individual variation in adult phenotypes.

96-8 Sondhi, Y*; Ellis, EA; Bybee, SM; Theobald, JC; Kawahara, AY; Florida International University, McGuire Center for Lepidoptera and Biodiversity, Florida Museum of Natural History, University of Florida; *yashsondhi@gmail.com*

Light environment drives the evolution of color vision genes in butterflies and moths

Opsins, combined with a chromophore, are the primary light-sensing molecules in animals and are crucial for color vision. Throughout animal evolution, duplications and losses of opsin proteins are common, but it is unclear what is driving these gains and losses. Light availability has been implicated and dim environments are often associated with low opsin diversity and loss. Correlations between high opsin diversity and bright environments, however, are tenuous. To test if increased light availability is associated with opsin diversification, we examined diel-niche and opsins from transcriptomes and genomes of 175 butterflies and moths (Lepidoptera). At least 14 independent opsin duplications are associated with bright environments. We estimated rates of opsin evolution and found that opsins from diurnal taxa evolve faster -

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at least 13 amino acids were identified with higher dN/dS rates. Modeling the 3D protein structure and analyzing the spatial distribution of these amino acids revealed that a subset of sites was close enough to the photopigment retinal to change the spectral sensitivity of the opsin. These results demonstrate that high light availability increases opsin diversity and evolution rate and can affect spectral tuning in Lepidoptera.

9-10 Sonner, SC*; Onthank, K; Walla Walla University; *sofia.sonner@wallawalla.edu*

Metabolic cost of octopus chromatophore system

Cephalopod color change is important for concealment and communication and is primarily controlled by chromatophores, pigment-containing sacs that expand and contract. The metabolic cost of the chromatophore system, and thus color change, in octopuses is unknown, but would reveal principles of how camouflage works, affects cephalopod energy budgets, and relates to their evolutionary history. In this study, we investigated the metabolic cost of chromatophore expansion in *Octopus rubescens* by performing respirometry on excised sections of chromatophore-containing skin and using light-activated chromatophore expansion (LACE) to periodically expand the chromatophores in the skin. We placed excised skin in a 612 μl respirometer and measured oxygen consumption while we stimulated chromatophore expansion by lighting the skin with intense blue light for 5 minute periods followed by 5 minute periods without blue light during which chromatophores contracted. The respirometer was under a dissecting scope, so micrographs could be taken of the skin. We used the micrographs to count the number of chromatophores expanded between periods when the blue light was on and off and used those counts to determine oxygen consumption per expanded chromatophore. We used whole preserved octopuses to estimate the total number of chromatophores on a whole octopus, and thus relate chromatophore oxygen consumption to total metabolic rate.

23-10 Sordilla, S*; Schulz, A; Hu, D; Brown University, Department of Ecology and Evolutionary Biology, Georgia Tech, School of Mechanical Engineering, Atlanta, GA, Georgia Tech, Schools of

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Skin morphology and microstructure in the elephant trunk

The skin of the elephant trunk must satisfy many functions: it must shield from the sun, protect against vegetation, and be flexible to allow the trunk to stretch. However, little is known about the morphology and micro-structural properties that help enable these tasks. In this experimental study, we dissect trunk samples from a deceased African elephant (*Loxodonta Africana*) and perform staining and second-harmonic imaging microscopy. The dorsal epidermis is ten times thicker than ventral epidermis in order to protect the trunk from the elements and physical contact with objects. We identify orientation of collagen fibers throughout the trunk, in particular in wrinkles and folds, and hypothesize how their directionality relates to the mobility of the trunk. Overall, the elephant skin bears similarities to human plantar skin in that morphology and composition play distinct and complimentary roles in allowing a broad range of functions of the trunk.

S9-3 Sorensen, PW*; Levesque, H; University of Minnesota; *soren003@umn.edu*

Blood-borne prostaglandin F2a causes female goldfish to become responsive to an androgen sex pheromone released by males

Although blood-borne prostaglandin F2a (PGF2a) is known to synchronize ovulation with sex pheromone release and female sexual receptivity in many fishes, how it enables female receptivity is not understood. This study examined the possibility that one way PGF2a acts is by altering how female fish perceive pheromonal odors. Specifically, we addressed the possibility that mature male goldfish release a distinctive androgen-based odor which only goldfish with elevated PGF2a discern as a sex pheromone. Testing behavioral responses of both PGF2a-injected and saline-injected females in a maze, we discovered that while the latter were attracted to the odor of both immature and mature goldfish of both sexes, PGF2a-injected goldfish were only attracted to the odor mature males. Next, we discovered that androstenedione (AD), a C19 steroid known to be detected by the goldfish olfactory system, is part of this male odor. Not only was AD moderately attractive to PGF2a-injected females, but it became highly attractive when added

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to odor of immature goldfish odor that had previously been unattractive showing it is part of a mixture. Species-specificity was later demonstrated in behavioral tests which added ng quantities of AD to the odor of several other fishes but found only the odor of goldfish to be fully active. Both PGF2aand AD are common fish hormones and it seems reasonable to ask whether they might also play dual overlapping roles as pheromones and hormones mediating reproductive synchrony in other fishes. (Supported by the National Science Foundation).

73-12 Soto, D*; Goldman, DI; Georgia Institute of Technology; *dsoto7@gatech.edu*

Enhancing legged robot navigation of rough terrain via use of a tail

Robot locomotion across complex terrain has been widely studied for cases where the robot is much larger than obstacles or when the obstacles are much larger than the robot (e.g. climbing). Less is known about locomotion in environments where obstacles are of similar size to the locomotor; the most studied schemes rely on vision to map the terrain for appropriate footholds. Here we take a different approach, augmenting the emergent high-performance capabilities of a compliant-legged robot with a simple controllable tail. The quadruped robot (L=27cm, m=2.8kg, limb length 8cm) uses a diagonal couplet gait to locomote at 0.15 BL/sec on flat ground. When challenged by a 160cm long 80cm wide terrain composed of blocks with heights chosen from an inverted Gaussian distribution centered around the limb length, the robot suffers failures consisting of limb jamming. Controlling the tail via periodic taps improves performance, allowing the robot to successfully traverse the terrain in 2/46 trials via controlled disturbances to decrease probability of jamming. Inspired by this, we implement a controller which senses high current draw associated with limb jams which further improves performance (3/25 trials successful).

52-8 Souto, C*; Martins, L; Smithsonian Institution, Washington, DC, Museu de Zoologia, Universidade de São Paulo; *AlvesSoutoC@si.edu*

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The macrostructural anatomy and functional morphology of dendrochirotid sea cucumber's (Echinodermata) calcareous rings

Despite descending from heavily calcified ancestors, the holothuroid skeleton is fully internal and composed of microscopic ossicles and a ring of plates bound by connective tissue, the calcareous ring. The calcareous ring provides support for the water vascular system, nerve ring, pharynx and tentacles, and is a point for insertion of musculature. Still, it is one of the least studied structures of the holothuroid's body. Here, we used high-resolution μCT images to describe the anatomy and functional morphology of the calcareous ring macrostructure of eight phylogenetically diverse dendrochirotid species. The structures observed were highly variable at the subfamily level, especially at the point of tissue attachment. To aid future phylogenetic studies, we listed 23 characters and performed a preliminary cladistic analysis. The two topologies obtained support the claims that the simple, cucumariid ring is ancestral to the mosaic-like phyllophorid ring; however, they did not support the monophyly of this cucumariids. They also did not support the family Sclerodactylidae, which was described based on the ring morphology and whose subfamilies are nested within the Phyllophoridae as traditional classifications suggest. Differently from the ossicles, which are highly homoplastic, the general homoplasy index of the calcareous ring characters was relatively low. This result highlights the importance of this structure for phylogenetic inference. Unfortunately, time since collection, rough collection methods and fixation can damage the skeleton, and the calcareous ring is often overlooked in taxonomic descriptions. This is the first broad comparative study of the calcareous ring. We hope that the data presented here will improve our understanding of holothuroid relationships and facilitate studies on holothuroid biology and evolution.

3-5 Spagna, JC*; Lewin, D; William Paterson University; *spagnaj@wpunj.edu*

Minimum requirements for an effective web in the grass spider Agelenopsis pennsylvanica

Grass spiders (Araneae: Agelenidae) make flat, non-sticky webs that extend outward from a funnel. To capture prey, spiders hide in the funnel and when a small arthropod lands or falls onto the webs'

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surface, they run out of the funnel and bite the prey before the prey can walk or fly off the web surface. These webs can last weeks or months and the spiders continually add silk to them. We tested the hypotheses that prey capture performance would improve as the webs increased in thickness, and attempted to estimate optimal web age for prey capture purposes. We collected our local grass spider species (*Agelenopsis pennsylvanica*) and had them to build webs in optically clear plastic boxes, documenting web construction over the course of several weeks. Experimentally, we presented the spiders with prey items, and used high-speed video cameras (500 frames per second) to record their prey-capture behaviors. These included sensing, pursuing, and biting prey. As reported previously, the spiders frequently stop and reorient themselves while approaching prey (mean ± s.d.= 2.2 ± 1.6 stops per run). These corrections suggest that the vibrations are important for locating prey, but the system is imperfect. However, the spiders were equally likely to catch prey on webs of a wide range of ages (linear regression $p = 0.45$). Age of the webs had no impact on success rates of prey capture, nor did it impact maximum speed during prey approach (37 ± 15 body lengths/s), number of stops, nor magnitude of reorientation required to catch prey. Remarkably, for a web that is commonly built and reinforced over several weeks, the spiders could catch prey within one hour of commencing web construction, on a web consisting only of a small number of nearly-invisible threads.

89-4 Spears, S*; Kouyoumdjian, L; Pettit, C; Aubret, F; Gangloff, EJ; Ohio Wesleyan University, Station d'Ecologie Theorique et Experimentale du CNRS; *ssspears@owu.edu*

Plasticity in thermoregulatory behavior and performance in response to hyperoxia in a high-elevation specialist lizard, Iberolacerta bonnali

As climate change worsens and temperatures rise, the ability to respond to novel environments becomes essential. Ectothermic animals are particularly vulnerable to environmental changes, as they rely on their surrounding environment to maintain their body temperature. Ectotherms at higher elevations often face interacting challenges, including temperature extremes, intense radiation, and hypoxia. To study the effect of oxygen availability on ectothermic

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thermal physiology and performance, we collected Pyrenean rock lizards (*Iberolacerta bonnali*) from high elevation habitats (2254 m above sea level). Lizards were split into two treatment groups: one group was maintained at a high elevation (2877 m ASL) and the other group was transplanted to a low elevation (432 m ASL). While the effects of hypoxia on thermal physiology are well-explored, few studies have examined the effects of hyperoxia. We predicted that lizards transplanted to low elevation would exhibit higher thermal preferences and voluntary thermal maxima, as the increased oxygen availability would aid in maintaining a higher metabolism. Additionally, we predicted that maximum sprint speed and the optimal temperature for sprint speed would increase in the transplanted lizards, corresponding with a shift in the shape of the thermal performance curve. These results give insight into mechanisms underlying the thermal physiology of this high-elevation specialist. They can be used to predict potential plasticity in the physiological and thermoregulatory responses to the novel environments created by climate change.

103-7 Spence, M*; Rizwan, M; Rull, M; Konow, N; University of Massachusetts, Lowell; *meghan_spence@student.uml.edu*

Tongue in cheek: altered basihyal kinematics during food processing in terrestrializing Axolotls

Feeding in water versus on land imposes drastically different biomechanical challenges. Important innovations in the tetrapod feeding apparatus that facilitate terrestrialization include changes to tongue (hyobranchium) structure and function. In an aquatic environment, suction feeders use their often elaborate tongue system as a piston to draw water into the oropharynx, and the water in turn transports the food. By contrast, terrestrial tongues are primarily used for direct food manipulation during feeding, where they must precisely position food within the oropharynx between chews. We use biplanar videofluoroscopy to reconstruct 3D feeding kinematics of the tongue bone (basihyal) before and after induced metamorphosis in the Axolotl (*Ambystoma mexicanum*). We hypothesize that the piston-like hydrodynamic action of the suction feeding tongue involves minor out-of-the-plane deviations from pro-retraction, and elevation-depression. We also hypothesize that positioning food in occlusion during terrestrial

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chewing involves significantly more lateral tongue translation. Chew cycles in the aquatic Axolotl involve lateral tongue excursions of 0.199 ± 0.123 cm (mean ± S.D.). This result instills caution about interpreting suction feeding tongue action as a pure 2D action. In the terrestrial morph, lateral excursion is doubled (0.416 ± 0.149 cm), consistent with our second hypothesis. Early tetrapod fossils also demonstrate reductions in hyobranchial prominence, which may have facilitated increased lateral tongue excursions during chewing. Our lissamphibian feeding kinematics data may thus inform our understanding of how early tetrapods maintained feeding abilities as they invaded land.

77-6 Spillane, JL*; MacManes, MD; Plachetzki, DC; University of New Hampshire; *jlh1023@wildcats.unh.edu*

Sequencing and assembly of the Cerianthus borealis genome

Cnidarians form the sister group to bilaterians, and are a diverse phylum of animals. While there are many established model organisms within Cnidaria, there are still entire clades of organisms that are not represented in scientific studies due to the difficulty in sampling them or cryptic species and subspecies. Ceriantharia holds a unique position within Cnidaria, as the sister group to the remaining hexacorals according to the most recent phylogenomics analyses. Up to this point, however, the data available for cerianthids has been either transcriptomic, or from a small subset of genes. Here we report the draft genome from a cerianthid species, *Cerianthus borealis*. We used a combination of long and short-read sequencing technologies to produce a highly contiguous genome assembly that is 492 Mb in length and has a scaffold N50 of 396 kb. This genome will provide a resource to investigate questions about the evolutionary history of unique traits, gene families, and the phylogenomic distribution and ancestral state of mitochondrial genome structure within cnidarians, among others. Additionally, the low-cost rapid sequencing and bioinformatic workflow developed herein will be useful for future studies involving the sequencing, assembly, or annotation of other marine invertebrate genomes.

65-6 Spranger, RR*; Sinervo, BR; University of California, Santa

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Cruz; *rsprange@ucsc.edu*
Incubation temperature and maternal effects on thermal physiology in Ambystoma mexicanum
Endemic organisms, especially aquatic species with no ability to migrate, face extreme effects from climate change. One possible escape route is via maternal effects, but little is known about how amphibian mothers influence their offsprings' thermal traits. Facing thermal stress, a mother may program her progeny to cope with higher temperatures in the next generation, and then we would see between-generation plasticity. We study how Mexican Axolotl, *Ambystoma mexicanum*, mothers' might influence their offspring's thermal physiology through between-generation plasticity and incubation temperature. I genetically crossed *A. mexicanum* in a half-sibling design by pairing males with females from 18 and 21 C treatments to measure effects on progeny's thermal preference and critical thermal maximum. I measure maternal effect-driven plasticity among full-siblings from dams, while half-siblings are used to estimate additive genetic effects. Eggs were divided among 18 and 21 C treatments to measure effects of incubation temperature. We ran the offspring through thermal preference trials at 5 and 19 days old, and after dividing in a block design, at 33 days old, and then performed critical thermal maximum trials. By integrating thermal physiology with microclimate data to create hours of restriction functions, I model species persistence to understand how maternal effects influence extinction risk. Our preliminary results show that incubation temperature and mother's temperature affect offspring thermal preference. We also present a current extinction risk model for *A. mexicanum* with and without rescue from maternal effects. If between-generation acclimation can occur, it could be a potential mechanism to rescue ectotherms from climate warming.

17-1 St. John, ME*; Martin, CH; University of California - Berkeley; *stjohn3@berkeley.edu*
The specialists' guide to the novel niche—How shifts in aggression, feeding behavior, and mate preference contribute to scale- and snail-eating in pupfishes
Shifts in behaviors and morphology are often hypothesized to be involved in an organism's transition to a novel ecological niche,

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but the relative importance of each of these changes is still unknown. Here, we use a young adaptive radiation of *Cyprinodon* pupfishes to investigate which phenotypic shifts are necessary to occupy the ecological niches of scale- and snail-eating. There are currently several hypothesized origins for scale- and snail-eating that include shifts in: aggression, feeding kinematics and preference, mate preference, and craniofacial morphology. We investigate each of these hypotheses using behavioral and kinematic assays, transcriptomic data, and quantitative trait locus mapping. We found increased levels of aggression in both scale- and snail-eaters compared to generalists, suggesting that increased aggression is important to the occupation of both niches. Shifts in feeding behaviors were also important for both scale- and snail-feeding performance but shifts in morphology (i.e. larger jaws) increased scale-eating performance, while snail-eating performance was independent of the morphological shifts observed in the species (i.e. increased nasal protrusion size). Furthermore, generalist and snail-eating pupfish exhibited strong mating biases against scale-eating mates, suggesting that pre-mating isolation plays a larger role in occupation of the scale-eating niche. Ultimately, we conclude that shifts in behaviors such as aggression and feeding preference/kinematics may be universally important for colonizing a new ecological niche, but that additional shifts in morphology or pre-mating isolation are needed to occupy a truly novel niche such as scale-eating.

73-13 St. Pierre, R*; Bergbreiter, S; University at Buffalo, Carnegie Mellon University; *ryans@buffalo.edu*

Legged locomotion at low Reynolds numbers: limitations on insects and microrobots

Forces imposed on legged locomotors from the physical environment sets inherent constraints on the locomotive behavior of the system. Insects are some of the fastest terrestrial legged locomotors relative to their sizes, reaching relative locomotion speeds in excess of 100 body lengths per second. At these small sizes, the low body inertia is accelerated and decelerated quickly as legs push against the ground. At the same time, surface forces, such as friction and viscosity, emerge with similar magnitudes as inertial forces. Therefore, small scale, legged insects are affected by both

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inertial forces and surface forces during locomotion, imposing a set of physical constraints that legged locomotors must navigate. Here, we use the Reynolds number, a non-dimensional number that quantifies the ratio of the inertial forces to environmental viscous forces to identify legged locomotive systems that are limited by surface forces. A fit to the log-transformed body mass and Reynolds number for biological legged locomotors from 3.7 g to 30 μg shows a higher exponential relationship of Reynolds number to the body mass ($mb^{0.70}$) compared to inertial scaling ($mb^{0.50}$), indicating an effect from surface forces on locomotive performance. We utilized a physical microrobot model (1 mg) running at biologically relevant speeds (up to 45 body lengths per second) and quantified inertial and viscous forces in the system, and found limitations in stride frequency and locomotion speed from joint viscosity. Scaling simple locomotion models also reveals transition points where viscous forces ultimately limit locomotion. While surface forces are dissipative and would seemingly impede locomotion, they also increase the stability of a system, and have implications for control in rapid locomotion of insects and microrobots.

S4-5 Staab, KL; McDaniel College; *kstaab@mcdaniel.edu*
Implementing fabrication as a pedagogical tool in vertebrate anatomy courses: motivation, lessons, and outcomes
Fabrication can be employed in vertebrate anatomy courses in various ways to enhance student learning. Here I share how I converted an anatomy lab at a small liberal arts college into a makerspace to spark student creativity using inspiration from vertebrate animals. Learning science in informal environments and specifically in makerspaces has been shown to promote equity and increase motivation to study science. Examples here emphasize accessibility for diverse learners, including strategies for instructors to ensure ease of student access to 3D technology. Scaffolding introduction to software, materials, and skills allows students to fail early and safely in low-stakes assignments, building confidence and expertise. Adding this structure to biology courses helps all students but it benefits underrepresented students even more, further closing opportunity gaps. A way to increase student motivation is to give choices in what they learn.

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In a semester-long research project in an introductory biomechanics course, students investigate, write about, and build models of animal anatomy of their choice. They use simple materials, crafting supplies, household tools, and/or 3D printing to demonstrate structures of interest, enhancing understanding of the physical principles of animal form and function. Given increased availability of CT data online, students can download, analyze, and 3D print skeletal models of both common and endangered animals. Comparative anatomy students reported they had increased motivation to study intricate skeletal anatomy simply by manipulating bones in a 3D software assignment. Indeed, students performed better on exam questions on their assigned bones as compared to controls and this has potential to scale. All examples are low-cost, accessible options to boost learning of anatomy.

89-8 Stadtmauer, DJ*; Wagner, GP; Yale University; *daniel.stadtmauer@yale.edu*

How to exhibit "positive tolerance": Lessons from the mammalian uterus

In response to environmental stress, cells, like organisms, can respond in two ways: defense by direct resistance against the stressor, or tolerance by increased conformity to the stressor. These strategies have been termed Cellular Life History Programs. The defense program entails protein kinase B (PKB) signaling, aerobic glycolysis, and inflammation, and the tolerance program entails cyclic AMP/protein kinase A (PKA) signaling, catabolism, and oxidative stress resistance. The differentiation of the decidual stromal cell, a uterine cell type unique to placental mammals which functions to support the fetus, occurs in response to the stress of a fetus. We established a model system to differentiate endometrial fibroblasts with signals mimicking pregnancy, the inflammatory mediator prostaglandin E2 and the hormone progestin. Single-cell RNA sequencing revealed that human uterine cells develop through successive stages representing these life history programs: an initial activated defense state transitions into to a pro-tolerance state. This switch is regulated by an evolutionarily derived mechanism, the progesterone-mediated switch to an alternative receptor for prostaglandin E2, subtype 2 (EP2). This receptor specifically activates PKA, helping channel

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the cell towards tolerance, whereas its paralog EP4 activates PKB. This receptor switch is absent in the opossum, a marsupial, whose endometrial fibroblasts instead mount a failed defense response ultimately leading to cell death. The evolution of pregnancy likely involved elaboration of the pro-tolerance life history program and its embodiment in a specialized cell type. Tolerance of the fetus, long held to be paradoxical, emerged as an elaboration of this ancient cellular program - an active, strategic, and positive form of tolerance - rather than only suppression of defense.

BSP-6-2 Stager, M*; Senner, NR; Swanson, DL; Cheviron, ZA; University of South Carolina, University of South Dakota, University of Montana; *maria.stager@gmail.com*

The environmental drivers of variation in Junco physiological flexibility

Theory predicts that phenotypic flexibility will evolve in variable yet predictable environments. What is less well understood is how the relative degree of flexibility in flexible traits might relate to the environment, however. It has been proposed that the degree of flexibility exhibited by an individual will positively correlate with the environmental heterogeneity it experiences, yet there are few empirical examples to support this. To help uncover the mechanisms driving geographic variation in physiological flexibility, we integrated assays of population genetic variation with whole-organism measures of thermogenic performance and indices of environmental heterogeneity for individuals in the songbird genus *Junco* . Juncos inhabit a wide range of environments from montane forests of Central America to the taiga of northern Alaska, offering an opportunity to understand how environmental conditions may drive patterns in flexibility across this diverse group. We combined measures of thermogenic capacity for 292 individuals collected across the United States, 28,000 single nucleotide polymorphisms genotyped in 192 individuals, and laboratory acclimation experiments replicated on five Junco populations. Across their range, juncos: (1) differed in their thermal performance responses to temperature variation *in situ* ; (2) exhibit variation in their degree of thermogenic flexibility that correlates with the heterogeneity of their native thermal environment; and (3) harbor genetic variation that also correlates

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with temperature heterogeneity. Together, these results support theoretical predictions and suggest that thermogenic flexibility may play a key role in local adaptation in this broadly distributed lineage.

99-4 Staley, C*; Utsumi, K; Colorado State University, University of Kansas; *catherineastaley@gmail.com*

Social networks of the Atacamen Pacific iguana, Microlophus atacamensis

Animal social networks describe the relationships that connect interacting individuals. While understudied in reptiles, a close examination of lizard society can reveal a remarkably complex social network. We compared variation in the interactions between *Microlophus atacamensis* on rock outcrops to interactions among the same individuals in the adjacent boulder field, using data from each habitat separately as well as using all the interactions to describe their social network. We tested the hypothesis that boulder fields serve as display arenas to both cement and expand social relationships. *M. atacamensis* is a species of lizard endemic to the rocky coasts of the Atacama Desert, Chile. To examine their social network, we recorded every interaction that occurred during a 30 to 120-minute survey period from fixed locations that allowed 3 - 5 observers to view the entire boulder field. Simultaneously, one observer surveyed the rock outcrops that bordered the boulder field to determine occupancy and to record any interactions that occurred on the rocks during the same survey. We classified five interaction types: chases, displacements, fights, retreats, and associations. We examined network indices of centrality by sex and body size including degree and betweenness, as well as measures of association tendencies such as homophily and assortivity. Our data indicate that the social network of *M. atacamensis* closely resembles that of a harem, with one or two males occupying a rock outcrop along with several females. Rock outcrops appear to serve as territorial sites whereas boulder fields act as display venues into which individuals descend to interact with one another.

97-9 Stanchak, KE*; Miller, KE; Lumsden, EW; Davis, CG; Brunton,

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BW; Perkel, DJ; Department of Biology, University of Washington, Department of Biology, California Polytechnic State University, Departments of Biology and Otolaryngology, University of Washington; *stanchak@uw.edu*

Immunohistochemical exploration of hypothesized mechanosensory features in the avian lumbosacral spinal cord

The avian lumbosacral spinal cord has several distinctive morphological features that are collectively referred to as the lumbosacral organ (LSO). The LSO is hypothesized to serve as a second set of balance sensors, in addition to those in the inner ear. A few different mechanosensory mechanisms have been proposed for the LSO, including that deformation of the neural tissue or motion of cerebrospinal fluid stimulates sensory neurons within the spinal cord. To design effective experiments to distinguish among mechanosensory functional hypotheses, a deep understanding of the underlying neuroanatomy is required. Here, we present a preliminary immunohistochemical characterization of the LSO region of the avian spinal cord, with a focus on exploring sensory-related attributes. One notable finding is the presence of Myosin VIIa (Myo7a) immunoreactivity in cells near the central canal and the laterally-protruding accessory lobes. Another is the presence of Calcitonin gene-related peptide (CGRP) immunoreactive fibers that invade the dorsally-located glycogen body. Myo7a is associated with mechanosensory function in the hair cells of the inner ear, while CGRP in the dorsal horn is expressed in sensory afferent neurons. We discuss potential mechanosensory implications of these findings in the context of the overarching hypothesis that the avian LSO helps birds balance.

90-7 Stander, RM*; Cahill, AE; Albion College; *rms14@albion.edu*

Effects of road salt and its alternatives on freshwater invertebrates

Road salt (NaCl) administration has been an economically affordable and efficient solution to deicing the roads in the northern climate. NaCl lowers the freezing temperature of water, which accelerates the melting process of snow and ice. Once this chemical reaction occurs, sodium and chloride ions drain into the sewers, soil, and other freshwater systems, including throughout the State of Michigan. This salt contamination of freshwater environments

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comes in contact with and harms the existing aquatic life. Road salt deposition has produced ecological drawbacks in Michigan's freshwater. The purpose of this project was to examine NaCl's effect on common Michigan invertebrates which included *Daphnia, ostracods, midge larvae and earthworms by testing ice melting alternatives. Alternatives used in this experiment included Beet-It Ice Melt, pickle juice, sugarcane molasses, and sand. We conducted a second experiment in which we exposed the animals to a range of NaCl concentrations, in hopes of identifying a threshold concentration that allows for survival in salty environments. In both experiments, we measured survival and reproduction of the organisms in order to demonstrate the detrimental effects of road salt pollution. In both experiments, we found that the organisms responded differently to all deicer alternatives. Only Daphnia was significantly affected by road salt. The other invertebrates were not significantly affected by any treatment, including high concentrations of road salt, demonstrating interspecific differences in response to salt. This research allowed us to investigate a less harmful alternative to road salt in hopes of minimizing the endangerment and potential extinction of ecologically important invertebrate species.*

S3-9 Stankowich, T; California State University Long Beach; *theodore.stankowich@csulb.edu*

Don't touch! The function and evolution of defensive spines in mammals

Animals employ a wide array of defensive strategies to avoid being killed by predators. Many taxa bear sharp spines that serve a variety of defensive (and non-defensive) functions including preventing biting and grabbing, hindering swallowing, and resisting extraction. The morphology and overall robustness of defensive spines vary across taxa from long and thick (echidnas and porcupines) to short and thin (tenrecs and hedgehogs). This talk will explore the ecological, physiological, and behavioral factors that promote the evolution of spiny defenses as well as explore other traits that may evolve with spines in a correlated fashion. These may include aposematic warning coloration, locomotion style, metabolic rate, and diet. The function and evolution of spines will be compared to that of plate-style body armor (e.g., armadillos),

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and a general summative framework will demonstrate how the integration of evolutionary and biomechanical studies of spines can help us better understand the selective factors that shape them.

29-10 Stanton, DS*; Hurlbert, JC; Smith, JP; University of Florida, Winthrop University; *stantond2@ufl.edu*

The Acoelomorphan circadian clock reveals a critical point at which the PER/ CRY heterodimer evolved as the negative regulator in Animalia

Circadian oscillations are ubiquitous among organisms and rely on a positive element being repressed by a negative element to complete a transcription-translation feedback loop (TTFL). The complexity of this loop and secondary loops have evolved over the animal linage. The circadian clock mechanism is well described in many deuterostome and higher protostome species, particularly in insects. Less is known in lower animals; however, the circadian clock mechanism has been at least partially elucidated in a few key species of sponges, cnidarians, annelids and crustaceans. Here, we identified the negative regulators PERIOD and CRYPTOCHROME of the Acoelomorphan, *Isodiametra pulchra* . The Acoelomorpha are an especially important group to study because are the common ancestor of the protostome-deuterostome bifurcation, retaining characteristics of both deuterostomes and protostomes that have made an agreement on their positioning difficult. We previously reported the discovery of a primitive PER In this species, pin-pointing the origin of PER in the Animalia. Here, we report the identification of a CRY ortholog using bioinformatic approaches. We also used predictive modeling to test if *I. pulchra* PER and CRY can form a heterodimer. Using HADDOCK predictive modeling we found a conserved loop containing TRP253 on the *I. pulchra* PER homologue that fits into a binding pocket on *I. pulchra* CRY homologue. Ongoing research from our lab is using *E. coli* to express these proteins for a Surface Plasmon Resonance assay to determine if these proteins bind to validate the *in silico* HADDOCK results.

27-3 Stark, G*; Levy, O; Tel Aviv University, School of Zoology, Tel Aviv, Israel; *gavinstark89@gmail.com*

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Climate change and ecological interactions: How vegetation cover affect the performance of desert lizards?
Global warming affects how organisms interact with each other and with the environment they inhabit. The ability of organisms to compensate for climate change highly depends on the ability of other species to make similar compensations. Hence, we need to look beyond single-species studies and ask how a species depends on other species for survival, especially where some of the other species are predicted to decline under climate change. To fill this gap, we quantify how lizard's physiology is affected by the availability of vegetation cover and insect abundance in a desert community. In particular, we studied a desert lizard (""*Messalina bahaeldini*"") and its interactions with the local vegetation, which inhabits the Judean desert in Israel. First, we used a drone to map the vegetation cover in two study areas at a resolution of 3 cm. Next, we collected 81 lizards, measured their fat mass using Dual Energy X-ray Absorptiometry (DEXA), and calculated the percentage of vegetation cover around the collection coordinate of each lizard. Finally, we tested how fat mass is affected by vegetation cover at different radii (1-100m) from the lizard, and by the Julian day. We found that vegetation cover within a 10m radius from each lizard is the best predictor for lizards' fat mass, compared to other radii. Specifically, the fat mass increased with vegetation cover, particularly during the summer. Incorporating the results of the model with other levels of interactions (such as prey abundance) will enable us to estimate the importance of the stability of such ecological interactions in the desert system of lizards and better predict the biological impacts of climate change.

39-1 Stayton, CT; Bucknell University; *tstayton@bucknell.edu*
Consistent but weak evolutionary correlation between predator bite force and turtle shell strength: complex selection in a simple defensive armor
Predators exert strong selective pressures on prey, which respond by evolving defenses. Armor is one such defense which can vary in the presence of different levels of predation pressure. However studies on this have been uneven in scope, limiting their usefulness for deriving general conclusions concerning predator

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effects on armor evolution. This study investigates the evolutionary covariation of turtle shell strength and the bite forces of turtle predators across the turtle phylogeny. Shell strength is assessed through finite element (FE) modeling. Predator overlap with turtle ranges is assessed through GIS and bite forces are collected from the literature; these are combined to produce two measures of predation pressure. Evolutionary correlations are consistently seen between all variables, indicating that strong predators may impose selection pressure for increased shell strength. However, these correlations are consistently weak. A number of potential explanations could account for this: trade-offs between turtle shell strength and other shell functions, selection in response to predation risk rather than predator presence, and selection acting on shell strength in juveniles or subadults rather than adults. Trade-offs have been documented, and variable strength of selection in different environments support the second hypothesis. Future work is necessary to support the third hypothesis. This study joins others in demonstrating that the evolution of armor has a complex relationship with predation.

77-1 Steck, M*; Sung, JY; Outomuro, D; Maddison, WP; Morehouse, N; Porter, ML; University of Hawai'i at Mānoa, University of Cincinnati, University of British Columbia; *steck4@hawaii.edu*

Opsin evolution and color vision in jumping spiders

Male jumping spiders (Salticidae) often exhibit elaborate courtship displays that incorporate colored body surfaces. The colored ornamentations used in these displays in some species may have implications for the evolution of color vision across the family. Previous work has identified up to four visual opsins (*Rh1-4*) from salticid visual systems, of which only two are expressed in the retinas of the principal eyes. In this study, we investigated the potential evolution of color vision in the family Salticidae using transcriptome data from 20 species to identify opsin transcripts. Three clades of visual rhabdomeric opsin transcripts were consistently identified in each species: *Rh1*, *Rh2*, and *Rh3/Rh4*. Non-visual opsin transcripts were also identified including peropsins, pteropsins, arthropsins, and *Rh7* opsins. Sex-specific opsin expression co-occurred in several species where *Rh1* transcripts were duplicated. Future work will use

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antibodies generated from *Hasarius adansoni* visual opsins to identify expression patterns among eyes and to make predictions about the evolution of color vision within this group. The results presented here suggest that color vision may be more prevalent in salticid vision than previously thought and that duplications of *Rh1* have occurred in several species.

MOORE-1 Steele, CM; Stanford University; *gillnash@stanford.edu*

Stereotype threat and identity threat: The science of a diverse community

Drawing on stereotype threat and social identity threat research, this talk will address the why, what and how of diverse learning communities: why they are important, a working hypothesis about what is critical to their success and what research reveals about how to achieve that success. The talk's practical aim is to identify features of diverse learning communities—schools, universities and academic disciplines—that while good for all students, are especially helpful for minority students generally, and for women in STEM fields. The talk will also explore the psychological significance of community and its role in learning.

41-4 Steffenson, MM*; Lucas, L; St. Edward's University; *msteffen@stedwards.edu*

The effect of learning space management on student engagement

The idea of learning spaces is that the physical space in which a classroom is conducted can have a dramatic influence on how well students learn. In fact, some studies have shown that appropriately designed social learning spaces enhance student engagement by fostering social interaction and active learning. As a result of such studies, many higher institutions are making it a priority to evaluate existing spaces and upgrade them to better promote active learning strategies. In summer 2019, John Brooks Williams - North 202 at St. Edward's University in Austin, TX was the focus of such an upgrade. These upgrades included moveable desks and chairs, a mobile teaching podium, banks of dry erase boards on two walls, and the installation of an addition smart projector (EPSON BrightLink Pro) so that annotations can be projected and read on three walls of the room. Using a timed observation protocol (Escala Educational

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Services, LLC), student engagement from Panopto-recorded lectures were analyzed to assess the level of student engagement in the classroom pre- and post-modification of the learning space. We found that students spent a higher proportion of time participating in mid- and high-level engagement practices when the learning space was modified to facilitate active learning more effectively. The learning space upgrade that students identified as having the most impact on their learning experience was the integration of small banks of dry erase boards. Students also identified that having multiple viewing surfaces for projectors was extremely helpful, even if said surfaces were not smart board enabled.

S8-7 Stellwagen, SD*; Burns, M; University of North Carolina at Charlotte, University of Maryland, Baltimore County; *sstellwa@uncc.edu*

The genetics of sticky: comparing glue sequences across multicellular eukaryota

Many eukaryotic organisms produce glues that function in a variety of ways, including prey capture (e.g. spider webs and sundews), defense (e.g. centipedes and hagfish), and most commonly, substrate attachment (e.g. mussels and caddisflies). The biomechanics and proteomics of many of these glues have been investigated; however, the genetics of a number of eukaryotic glues is still vastly understudied. Many of the genes that encode for glue proteins are extremely large (5-40 kb coding sequences) and repetitive, and only recently has long read technology begun to allow a description of their complete lengths and organization. This presentation reviews what is known about the genetics of sticky glues from a diversity of organisms, and describes recent progress in sequencing the aqueous glue of two spider species, the house spider *Parasteatoda tepidariorum* and bolas spider *Mastophora phrynosoma*, which have different web morphologies. The glues from these species vary greatly in length and repeat organization, which likely reflects variable selection pressures experienced by targeting different prey and employing different web structural strategies. Understanding the similarities and differences of animal glue genes will pave the way for biomimetic adhesives produced for a variety of unique purposes.

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49-9 Stevens, DR*; Wund, MA; Baker, JA; Foster, SA; Clark University, The College of New Jersey; *dalstevens@clarku.edu*
Stickleback populations experiencing northern pike invasion show more among-population level variation than those without
The phenotypic plasticity displayed by most phenotypes is thought to potentially buffer populations from novel environmental changes, or to even guide subsequent evolutionary responses. Behavior is often thought to be the most plastic phenotype, and the first phenotype to change or respond to sudden environmental changes. Thus, the degree of a population's behavioral plasticity should be under intense selection during environmental change. The threespine stickleback (*Gasterosteus aculeatus) populations residing in southcentral Alaska are currently experiencing an invasion from the predatory Northern pike (Esox lucius). Multiple stickleback populations have potentially gone extinct following pike invasion; thus, stickleback populations are likely to be under intense selection pressures following pike invasion. In this experiment, we asked how the developmental, and activational plasticity of threespine stickleback behavior has evolved following invasion by northern pike. We did this by exposing stickleback from three populations with and without northern pike to chronic artificial predation events during the first year of development and asked how their behavior differed to those that were not exposed. Our results suggest that long-term predation exposure does not influence stickleback behavior. Furthermore, we found that the degree of behavioral plasticity in stickleback antipredator behavior was much more variable among populations with invasive pike, than those without invasive pike, with the both the most plastic and least plastic populations being pike-invaded populations. In this talk we will discuss these results in the context of how phenotypic plasticity evolves, and how likely it is that populations of the same species evolve, and evolve in the same manner, in response to novel environmental changes.*

110-2 Stewart, TA*; Yoo, I; Upham, NS; The University of Chicago, Chicago, IL, Arizona State University, Phoenix,

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AZ; *tomstewart@uchicago.edu*

On the coevolution of mammae number and litter size

The hypothesis that mammae number correlates with the offspring number of species can be traced back to Aristotle. However, it has never been tested rigorously. Previous efforts to investigate the relationship between these traits were of limited taxonomic scope to address mammal-wide patterns and did not consider the effect of phylogeny on species data. Here we comprehensively sample mammal diversity, analyzing data for 2,301 species, to ask: Do mammae number and litter size co-evolve and, if so, how? Using phylogenetic generalized least squares regression, we show that across Mammalia, mammae number evolves with an approximately one-to-one relationship with the maximum reported litter size of a species. Mammae number predicts litter size more strongly than other species level traits (adult body mass, gestation length, diet, and seasonality of contemporary geographic distribution) which is surprising given the usual emphasis on energetic traits and body mass to explain litter-size variation. Clades can diverge from these general patterns, revealing the influence of diverse life-history strategies upon mammary evolution. We argue that mammae number is an underappreciated constraint on fecundity and that its evolution has influenced the radiation of mammals.

22-7 Stewart, MT*; Wainwright, DK; Nikora, VI; Cameron, SM; Thunert, M; Stoesser, T; University of Aberdeen, School of Engineering, UK, Yale University, Peabody Museum of Natural History, USA, ThorLabs, Lübeck, Germany, University College London, Civil, Environmental & Geomatic Engineering, UK; *mstewart@abdn.ac.uk*

High resolution measurements of billfish skin roughness

Biological surfaces often exhibit roughness features across a wide range of scales, serving a multitude of functions from protective armour through to controlling heat and mass transfer rates at the surface of the organism. The significant positive impact that skin surface roughness can have on hydrodynamic performance of marine species has been demonstrated through numerous studies of sharks. These natural roughness patterns offer an ideal template for mankind to develop engineering surfaces with improved efficiencies for applications involving, for example, the transport of fluids

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through pipelines and channels. In this respect, the Billfish offer an interesting source to draw inspiration from. Their bodies are covered in distinctive roughness patterns yet, despite continuing efforts of researchers, the role that this surface roughness plays on their exceptional swimming capabilities remains poorly understood. The subsequent practical bio-inspired engineering applications that could follow also remain to be investigated. Two closely related reasons for this are identified. First, is a lack of detailed information on the three-dimensional morphology of billfish roughness, and second, is a lack of rigorous experimental investigation of the hydrodynamic properties of the roughness. An overview of existing knowledge of roughness in the Billfish is provided first. Strategies aimed at addressing these outstanding issues are then discussed, including recent developments in measurement capabilities. The discussions are supported with some novel measurements of sailfish, marlin and swordfish skin.

104-7 Stilson, KT*; Li, P; Laurence-Chasen, JD; Olson, S; Luo, Z; Ross, CF; The University of Chicago, Chicago, IL; *kstilson@uchicago.edu*

The role of inferior alveolar nerve afferents in control of jaw kinematics in Didelphis virginiana

Teeth are essential part of a sensory system for monitoring bite force and properties of the masticated food. The mandibular teeth are innervated by the Inferior Alveolar Nerve (IAN). Our study uses the XROMM workflow to track hemi-mandibular movements during mastication cycles by five opossums (*Didelphis virginiana*), and to test how IAN controls jaw kinematics. A helical axis method was used to calculate the axis of rotation of each hemimandible. In healthy individuals (with intact IAN), the axis of rotation is the same on both the left and right working sides (WS) and parallel and superior to the molar row during occlusion, and the molars were everting while translating lingually across the upper molars. The axis of rotation on the left and right balancing sides (BS) was medial to the anterior ramus and ran superio-anteriorly, moving the BS tooth row medially and the ramus laterally. However, after the left IAN was transected, the left and right hemimandibles exhibit different axes of rotation during WS occlusion. For the right hemimandible during right WS occlusion the axis of rotation is

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undefined (i.e., movement is too small to measure) or below the right hemimandible. The axis of rotation for the left hemimandible during WS occlusion is parallel and superior to the tooth row. These results suggest that bilateral sensory feedback through the IAN is important for control of hemimandibular rotation. Mastication is still possible without this feedback, but it is less efficient and differs from the intact condition. Grants: MRI 1338036, SR01DE023831-04S1, MRI1626552.

S6-8 Stoddard, MC*; Hogan, BG; Princeton University; *mstoddard@princeton.edu*

Spatiotemporal dynamics of a hummingbird courtship dive

Many animals have evolved signaling displays that combine multimodal components with dynamic motion. To understand the function and evolution of these displays, it is important to appreciate their spatiotemporal organization. Male broad-tailed hummingbirds (*Selasphorus platycercus*) perform spectacular U-shaped courtship dives over females, appearing to combine rapid movement and dive-specific mechanical noises with visual signals from their iridescent throats (gorgets). To understand how motion, sound and color interact in these complex displays, we obtained video and audio recordings of dives performed by wild hummingbirds. We then applied a multi-angle imaging technique to estimate how a female would perceive the male's iridescent gorget throughout the dive. We show that the key physical, acoustic and visual aspects of the dive are remarkably synchronized—all occurring within 300 milliseconds. Our results highlight the critical importance of accounting for motion and orientation when investigating animal displays: speed and trajectory affect how multisensory signals are produced and perceived.

96-4 Storks, L*; Leal, M; University of Missouri, Columbia, MO; *storksle@gmail.com*

Neuronal evolution across the Puerto Rican anole radiation

Vertebrate brains are extremely diverse in size, shape, and structure. Two of the primary factors contributing to such diversity are species ecology and evolutionary history. Historically, variation in neuroanatomy across vertebrates has been

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primarily evaluated at the level of absolute or relative size of the brain or its major regions. However, recent evidence has revealed that the size of a brain or brain region is not a reliable proxy of its underlying neuronal parameters, such as the number and size of neurons, which underly the function of the nervous system. West Indian *Anolis* lizards are an ideal system for untangling the effects of species ecology and evolutionary history on brain evolution. Within each of the major islands of the Great Antilles, *Anolis* have evolved into several ecomorph types, each specialized for a distinct structural habitat niche. Selection to exploit these habitat niches has resulted in convergence within species of the same ecomorph in aspects such as morphology, communication, and territoriality. Previous research has demonstrated that within the Puerto Rican radiation six species of anoles (*Anolis cristatellus, A. gundlachi, A. evermanni, A. krugi, A. pulchellus, A. stratulus*), belonging to three different ecomorphs, do not diverge in the volume of specific brain regions based on ecomorph or habitat complexity. We revisited this finding at a finer scale by characterizing the number and density of neurons and other cells in the telencephalon, cerebellum, and remaining brain areas to evaluate the potential effect of species ecology on brain evolution among these six species of Puerto Rican *Anolis*.

32-4 Strader, ME*; Speare, KE; Howe-Kerr, LI; Correa, AMS; Hofmann, GE; Auburn University, University of California Santa Barbara, Rice University, Rice University; *stradermarie@gmail.com*

Nitrate enrichment has lineage specific effects on Pocillopora adults, but little carry-over effects in larvae

Increases in ocean temperatures interact with spatially variable local stressors such as nutrient pollution to influence the prevalence and severity of coral bleaching. Nutrient pollution influences coral holobiont traits by altering the metabolic compatibility between symbionts and coral hosts. However, little is known about the molecular interactions between the coral host, symbiont community, and microbiome that contribute to the holobiont effects of nitrogen pollution as well as potential carry-over effects to the next generation. To test this, colonies of the brooding, vertically transmitting coral in the

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genus *Pocillopora* were enriched with excess nitrate in situ on the reef for one year and allowed to naturally planulate. Holobiont traits and coral host gene expression was characterized in adults as well as planula to address contributing factors of molecular disruption due to long-term nitrate exposure in the field. Despite substantial physical distancing between
collected *Pocillopora* colonies, clonality and chimerism were observed. Thus, both lineage and nitrate treatment specific effects on coral host gene expression were detected. This included enrichment of functional categories of genes associated with the synthesis of nitrogenous compounds and heavy-metal binding, genes previously linked to fine-scale tuning of micronutrient exchange with algal symbionts. Further, while nitrate effects were detected in adults, little to no effect was observed in the planula, suggesting coral host responses to nutrient pollution in the field are likely transient and potentially reversible.

12-2 Strock, S*; Colin, SC; Daniels, J; Costello, JH; Katija, K; Roger Williams University, Monterey Bay Aquarium Research Institute, Providence College, Monterey Bay Aquarium Research Institute; *scolin@rwu.edu*

Coordination of jet propulsion among physonect siphonophores

Physonect siphonophores are ubiquitous members of the epipelagic and midwater planktonic communities. Physonect swimming relies upon multiple individuals, termed nectophores, which are specialized solely for jet propulsion. Multiple nectophores and their central stem are collectively termed the nectosome and it is the sum necotosomal jet production that propels the entire colony during swimming. But are individual nectophores coordinated or acting independently? Using high-resolution video cameras attached to remotely operated vehicles (ROVs), we quantified the swimming behavior and kinematics of multiple nectophores of several physonect species in the Monterey Bay National Marine Sanctuary. Long-duration observations of individuals (> 1 hr.) showed that some species have consistent patterns of behavior that switch between drifting, swimming, and maneuvering. These different behaviors change the depth of siphonophores and determine vertical positions over time. Metachronal nectophore pulsation was frequent. In these cases, a leading nectophore contracted first and adjacent,

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trailing nectophores subsequently contracted with an almost-constant phase shift between individual nectophores. However, this was not true for all nectophores within a nectosome. We discuss the implications of these patterns for siphonophore swimming.

75-6 Struble, MK*; Gibb, AC; Northern Arizona University; *strublemikayla@gmail.com*

Locomotor spectra in basal vertebrates

The way an animal moves through its environment influences its success and reproductive fitness in its environment. As wildly as body plans, environment, evolutionary histories, and anatomy vary in these animals, so do too their locomotor patterns. Locomotion has been a difficult topic to study and historically has been tackled largely through the lens of identifying discrete locomotion patterns (gaits) which are biomechanically independent from other gaits a single animal may use. However, there is growing evidence that gaits are not as discrete as they are often treated, but rather exist on a kinematic spectrum where intermediate patterns exist. These intermediate patterns of locomotion, while utilized less often, provide an important framework for the evolutionary origins of the more commonly observed gaits and the adaptive pressures which helped shape them. To better understand how vertebrate gaits are related to one another, we investigated locomotor variation in leopard geckos, Eublepharis macularius, at a variety of speeds to test the relationship between inverted pendulum and spring-style gaits. Animals were filmed in dorsal and lateral view and 12 points along the animals' bodies which documented broad-scale movements were hand digitized in over 200 individual strides to enable us to identify kinematic trends associated with speed. Although the biomechanical divide between inverted-pendulum and spring-style locomotion in mammals is often relatively distinct, the relationship between these patterns of locomotion in Eublepharis macularius are less distinct and biomechanical patterns shift more gradually between fast and slow speeds. These results support recent research identifying transitional gaits as kinematic links between attractor gaits, the biomechanically stable patterns of locomotion animals often gravitate towards.

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107-1 Stupski, SD*; Schilder, RJ; Pennsylvania State University; *sqs6157@psu.edu*

Thermal plasticity in a combustion impaired dragonfly phenotype

One of the central challenges in thermal biology is understanding at a physiological level the mechanisms that underlay thermal performance curves. One hypothesis is that limitations in aerobic respiration are a key determinant of thermal performance. Here we test how reduction of energy flux through a metabolic pathway imposes a limitation on aerobic respiration and induces thermal plasticity in the flight musculature of the twelve-spotted skimmer, *Libellula pulchella* . *L. pulchella* often harbor a gut parasite that induces a metabolic syndrome phenotype, with the consequence of an impaired ability to metabolize fatty acids. We demonstrate that in an *in situ* maximally stimulated condition, the flight thoracic muscles of infected individuals are able to consume less oxygen than their healthy counter parts. We then demonstrate that this combustion impaired phenotype displays changes in thermal performance curves of mechanical lift production of wing-strokes in a tethered scenario. Finally, we show there are no salient features of differences in mitochondrial biogenesis or mitochondrial respiration between healthy and infected individuals under substrate saturated conditions that can explain a reduced capacity to consume oxygen.

20-8 Suarez-Rodriguez, MSR*; Tufarelli, AT; Suriyampola, PSS; Martins, EPM; Arizona State University, School of Life Sciences, Tempe AZ; *msuare14@asu.edu*

What about large waste? Effects of plastic bags on behavior of zebrafish

Littering continues to present a threat to natural environments as it may abruptly change the structure of habitats. Water bodies are among those habitats that receive most of the plastic residues that we generate. We now have a broad knowledge of how small, micro, and nano plastics affect the physiology and behavior of animals. However, larger pieces of waste may also alter behavior, interactions between animals, and interactions of animals with their environments. Here, we tested the impact of two common forms

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of plastic bags (floating and sinking; in pieces or in one sheet) on zebrafish behavior. Additionally, we used two different group sizes to test if the form of plastic affects differently a bigger or a smaller group of fish. We predicted that the treatment (plastic presentation and position) would affect how fast fish groups approached food, group cohesion, and space use. We found that larger groups were bolder than smaller groups, approaching food more quickly. In addition, fish were bolder when plastic bags were present, especially when the bags were near the surface of the water, creating a potential cover. Our experiment will provide the base to start exploring the effects that larger wastes could have on animals.

84-9 Suckow, N*; Pollock, HS; Kastner, M; Hauber, ME; Rogers, HS; UIUC, Iowa State University, Iowa State University; *nicolesuckow@gmail.com*

Angry birds: the personality of parental aggression and its fitness consequences in an island passerine

Animals can exhibit individually repeatable variation in behavior (i.e. personality), which may impact their fitness. A potential personality trait with clear implications for fitness is birds' parental aggression against nest predators. Dependent avian offspring experience the highest predation risk during their course of life, and consistent patterns of parental aggression can be important mediators of the young's fitness during these early stages. To test this hypothesis, we explored variation in parental aggression over the course of four years (2016-2020) in breeding pairs (n = 37) of Sali (*Aplonis opaca*), a locally endangered passerine on the Pacific island of Guam. Sali on Guam experience high rates of nest predation and fledgling mortality due to an invasive predator, the brown treesnake (*Boiga irregularis*). First, we quantified variation among breeding pairs of Sali in aggressive behavior towards human observers disturbing the nests, and found that an aggregate measure of aggression varied greatly among breeding pairs. Second, we calculated the repeatability of aggression as an index of personality and found that aggression was highly repeatable and consistent within breeding pairs, providing clear evidence of a pair-level personality trait. Finally, we explored the potential fitness consequences of variation in

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aggression for both nestlings and fledglings. We found that parental aggression was not correlated with either mean nest success or mean fledgling survival per pairs. Our findings suggest that although breeding pairs exhibit clear personalities with respect to aggression, this variation in personality is decoupled from offspring fitness, likely due to the lack of its effectiveness against the brown treesnake.

S6-6 Sung, JY*; Harris, OK; Hensley, NM; Chemero, AP; Morehouse, NI; University of Cincinnati, Cornell University; *chemeray@ucmail.uc.edu*

Beyond cognitive templates

The term 'cognitive template' originated from work in human-based cognitive science to describe a literal, stored, neural representation used in recognition tasks. As the study of cognition has expanded to non-human animals, the term has diffused to describe a wider range of animal cognitive tools and strategies that facilitate recognition and discrimination between external states to guide action. One potential reason for this non-standardized meaning and variable employment is that science has struggled to empirically locate or describe a direct template used in a nervous system, despite numerous predictions of its whereabouts and nature. We review and discuss the functional evidence for cognitive templates in fields such as perception, navigation, communication, and learning, highlighting any neural correlates within these studies. We find that the concept of cognitive templates has facilitated valuable exploration of animal behavior and cognition, but it has failed to lead to mechanistic support at the level of neurophysiology. This may be the result of a mislead search for a single physical locus for the 'template' itself. We argue instead that recognition and discrimination processes are best treated as emergent and, as such, may not be physically localized within single structures of the brain. We thus advocate for researchers to move towards a more process-oriented conception, especially when discussing functional employment of stored representations in cognitive tasks.

49-5 Sunga, J*; Webber, QMR; Humber, J; Rodrigues, B; Broders, H;

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University of Waterloo, Memorial University of Newfoundland, Government of Newfoundland and Labrador, Government of Newfoundland and Labrador; *jc2sunga@uwaterloo.ca*

Controlling for roost fidelity allows inference on the role of social preference in the organization of bat groups

Group behaviour is widespread among animal taxa and can be driven by passive and/or active mechanisms. In the former, animals aggregate due to the presence of a common resource while in the latter, individuals intentionally seek out conspecifics or even favoured social associates. The heterogenous distribution of resources common across many ecosystems can make it difficult to tease apart the relative roles of passive and active mechanisms in the organization of animal groups. Given the heterogenous distribution of suitable roosts and a dependency on conspecifics for thermoregulation, both passive and active mechanisms may influence the organization of summer maternity groups of temperate bats such as the little brown myotis (*Myotis lucifugus*). In this study, we assess whether roost-use decisions are driven exclusively by fidelity to roosts, or if social preferences may also influence an individual's decisions. To investigate this, we construct network models of roosting associations among bats in Salmonier Nature Park, Newfoundland, Canada. We construct null models that hold constant the proportion of times an individual uses a roost to approximate networks driven by only passive mechanisms. Evidence of network structure not explained by roost fidelity would suggest active mechanisms such as social preferences also impact individual roost-use decisions and thus the organization of bat maternity groups. As k-selected, long-lived animals, evidence of social complexity comparable to that of cetaceans, primates, and pachyderms would indicate intelligence as another characteristic of bats not expected by their small body size.

1-3 Suriyampola, PS*; Lopez, M; Suárez-Rodríguez, M; Ellsworth, BE; Conroy-Ben, O; Martins, EP; Arizona State University, Tempe, AZ; *psuriyam@asu.edu*

Blinded by darkness and contaminants: Impacts of multiple, interacting pollutants on visual behavior during early development

Anthropogenic activities often lead to alterations in natural environment via multiple routes. Simultaneous occurrence and

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interactions between multiple environmental perturbations may cause more complex influences on the way that animals respond than when being exposed to a single pollutant. The differences within phenotypes in organisms exposed to a single pollutant versus a mixture of different pollutants may depend on whether pollutants enhance, reduce, or have no impact on traits when they interact with each other. In our study, we investigated the interactive effects of deterioration in visual environment and exposure to a common contaminant, Bisphenol-A (BPA), on behavioral responses of larval zebrafish *Danio rerio*. Specifically, we tested the behavior of zebrafish larvae by exposing them to low-light conditions and environmentally relevant dosages of BPA for 7 days post fertilization. We found that the interaction between BPA and dim light conditions have the strongest influence on the visual behavior of zebrafish larvae as they were the least active and displayed the weakest response to an optomotor assay. Individuals exposed to either dim light conditions or BPA alone responded similarly to visual cues. With this study, we emphasize that pollution is almost never restricted to a single modality and we need to incorporate multiple pollutants to fully assess the impact that human activities have on behavior and performance of animals. Our findings provide evidence to explore how different modalities of human disturbances could interact to observe differences in behavior.

23-7 Sutton, GP; St. Pierre, R; Kuo, CY; Summers, A; Bergbreiter, S; Patek, SN*; U. Lincoln, UK, Carnegie Mellon, National Taiwan U., U. Washington, Duke U.; *snp2@duke.edu*

Devilish dynamics: precision mandible rotation without pins by ultrafast, spring-actuated trap-jaw strikes

Tiny trap-jaw ant (*Odontomachus brunneus*) mandibles close within an average of 77 μs, with angular velocities on the order of 104 rad/s (470,000 rpm). Based on a new empirical dataset of 99 strikes from 10 individual ants, we discover that the mandibles close in a circular arc as if constrained by a mechanical pin joint. However, trap-jaw mandibles lack such a mechanical pin joint. Kinematic models of elastic loading prior to strikes reveal that elastic energy is distributed and delivered equally between the muscle-apodeme unit and head capsule. Dynamic models show how this equal

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distribution of elastic energy storage results in a circular trajectory, with or without a mathematical pin joint constraint. Furthermore, deviations from equal energy allocation between the springs results in a net translation and disruption of the mandible's circular trajectory. Therefore, the circular trajectory of the mandible tips is a result of dual and equal elastic energy allocation between the muscle-apodeme unit and head capsule: the applied forces from their respective recoil accelerate the mandible in a circular trajectory with a fixed center of rotation yet without the constraints of a physical pin joint. These dynamics are analogous to "devil sticks" - juggling sticks that spin around a pivot defined by the applied forces of the juggler rather than by a joint constraint. The elegance and simplicity of using a partition of elastic energy to eliminate the need for kinematic constraints lead us to conclude that these devilish dynamics may be used by many spring-actuated biological systems.

S5-13 Swalla, BJ; University of Washington; *bjswalla@uw.edu*
The degenerate tale of ascidian tails
Ascidians are chordates, with a swimming chordate tadpole larva that has a distinct head and a tail. The head contains the small brain, sensory organs, including the ocellus (light) and otolith (gravity) and the presumptive endoderm, while the tail has a notochord surrounded by muscle cells and a dorsal nerve. There is one group of ascidians, the Molgulidae, where tailless larvae have evolved multiple times independently. My lab has been studying the evolution of tailless ascidian larvae in this clade for over thirty years and have shown that tailless larvae have evolved independently several times in this clade. Comparison of the genomes of these two species reveals much synteny, but there have been insertions and deletions that disrupt genes in the tailless species, *Molgula occulta*. Genomics and transcriptomics show that there are a number of expressed pseudogenes in the tailless embryos, and hybrid features are due to the intact genes from the tailed species being expressed in the tailless species. Yet we find that the notochord gene network is essentially intact, although the notochord does not converge and extend and remains as notoball in the tailless embryos. We expect that eventually many of the larval

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gene networks will be lost in tailless ascidians and the larval body plan abandoned, so eggs will develop directly into an adult.

51-1 Swiderski, DL*; Zelditch, ML; University of Michigan, Ann Arbor; *dlswider@umich.edu*

The adaptive landscape for jaw morphology in heteromyid rodents

A long-standing question in community ecology needs an evolutionary perspective to answer: How can so many species coexist in such unproductive environments as deserts? Ecologists have proposed assembly rules that predict how species could be added to communities, framed in terms of functional groups within guilds, specifically, that as species richness rises, new functional groups are added to a community until all are present before any are repeated. The challenge is to classify functional groups within guilds, using an objective and quantitative method. We propose that functional groups can be characterized as distinct adaptive peaks. Heteromyid rodents are a classic model system for testing rules, but only a narrow part of their range has been sampled intensively. It is not clear whether (or how) to generalize the postulated functional groups beyond the southwestern US. Here we analyze the adaptive landscape of Heteromyidae, taking as a starting point the idea that all belong to the same dietary guild, within which resources are partitioned mainly according to body size, but locomotory behaviors also partly determine access. We find that dietary adaptations are far more complex. Our analysis reveals five adaptive peaks for mandibular shape, and four for size. The peaks for the two traits are not concordant, mainly because of heterogeneous adaptations of the bipeds. Miniature bipeds converge towards mid-sized quadrupeds in shape, one giant biped also diverges in that direction but most are similar to mid-sized bipeds and have the same size but not the same shape as the mid-sized quadrupeds. Although locomotory mode obviously affects limbs and posture, it also has consequences for bullar morphology and thus for jaw shape, weakening bite which is differentially compensated in the giants and miniatures.

56-3 Swiney, PA*; Hedrick, TL; Gosdin, LR; Bellah, JR; Hopkins, AW; Raghav, V; Auburn University, Auburn, AL, The University of North

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Carolina at Chapel Hill, Chapel Hill, NC; *pas0018@auburn.edu*

Preliminary analysis of the aerodynamic responses of a red-tailed hawk traversing a vertical gust

This research adopts a bioinspired approach to improve how unmanned aerial vehicles (UAVs) and small aircraft fly by studying the aerodynamic responses of a red-tailed hawk (*Buteo jamaicensis*) when flying through a vertical gust. Red-tailed hawks remain stable and mitigate strong wind gusts that small aircraft struggle to fly through. However, the specific maneuvers that hawks perform to stabilize within natural or artificial wind gusts are not fully understood. To study these aerodynamic responses in a controlled environment, a flight-testing arena was developed. Four industrial fans placed perpendicular to the hawk's flight path were used to produce an average vertical gust velocity of 6.5 - 8.5 m/s at 0.8 m above the fans, the location the hawk flies at. This uniform gust region was introduced in the flight path, encompassing the entire wingspan of the hawk. Hawks normally fly at 10 - 18 m/s at level flight, making the gust magnitude between 36% and 85% of the hawk's flight speed. The gust responses were recorded using calibrated multi-camera videography from two GoPro Hero 6 Black cameras at 240 frames per second. The hawk's beak, tail, wings, and wrist were tracked in 3D to study the pitching response of the hawk when flying through the vertical gust. Tracking these specific points on the hawk will provide knowledge about how red-tailed hawks can morph their wings and tail to mitigate strong wind gusts while their body remains stable. This presentation reviews the experiment methodology and discusses some preliminary tracking data of the hawk's responses to vertical gust events.

7-3 Swinsky, CM*; Hastings, BT; Jackson, BE; Longwood University, George Mason University; *jacksonbe3@longwood.edu*

Markerless automated kinematic tracking of wild birds in agonistic flights

Studying non-locomotor uses of locomotor appendages can provide insight into the role of functional trade-offs in the evolution of animal anatomy. Bird tails have obvious aerodynamic functions, but they can also serve as potentially conflicting signals in territory defense, courtship, or predatory avoidance behaviors. To look for evidence of non-aerodynamic tail function in flying birds, we used

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multiple high speed cameras to record wild American Goldfinches (*Spinus tristis*) during individual and agonistic flights at established bird feeders. We reconstructed their three-dimensional movements based on a wand calibration in Argus (which uses direct linear transformation, DLT). Quantifying such variable behavior requires larger sample sizes than traditional lab-based biomechanical studies. To automate markerless digitizing, we trained two levels of DeepLabCut models, and developed custom code modules to convert data between DLT and DeepLabCut formats. The first model tracks each bird in each camera view, finds bounding boxes around each bird, and uses the output to create cropped videos for each bird. The second model performs detailed tracking of important kinematic landmarks on each bird in the cropped videos. Using cropped videos allows for faster and more accurate landmark tracking than running DeepLabCut on full resolution videos. Another module then rescales the coordinates from the cropped videos to full dimensions, converts the data format from DeepLabCut to DLT, and uses Argus to perform the 3D reconstruction. All custom code is available on GitHub. We found evidence of both aerodynamic and behavioral signaling functions of bird tails; for example, goldfinches fan and depress their tails during deceleration, and exaggerate those motions during agonistic interactions achieving greater decelerations.

S6-5 Symes, LB*; Madhusudhana, S; Martinson, SJ; Kernan, CE; ter Hofstede, HM; Center for Conservation Bioacoustics, Cornell Lab of Ornithology, Cornell University, Center for Conservation Bioacoustics, Cornell Lab of Ornithology, Cornell University, Dartmouth College, Dartmouth College; *symes@cornell.edu*
Sexual selection, natural selection, and artificial intelligence: Implementing technological advances to understand variation in signaling behavior
One of the most fundamental features of communication is when and how often a signal is repeated. Historically, limitations on observation time and monitoring technology have made it difficult to quantify and compare differences in signal activity across a community of species to generate and test hypotheses about how often signals are produced (signaling rate) and the daily duration of activity (signaling window). Advances in monitoring equipment

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and data processing are opening new avenues for research on signaling investment. Here, we assess potential drivers of signaling rate and signaling window using two complementary types of data: 1) automatic detections (using machine learning) of calls in soundscape recordings and 2) 24 hour recordings of focal individuals.

We focus on a community of Neotropical forest katydids on Barro Colorado Island in Panama. This community contains at least 80 species that vary dramatically in signaling rate and signaling window. Some species produce more than 10,000 calls per day. Other species produce less than 30 calls/day with each call lasting less than 50 ms, generating a total of less than two seconds of sound per day. Some species signal 24 hours a day, while other species signal during a window of a few hours. Using machine learning and focal recording data, we assess correlations and patterns in signaling investment, signal design, morphology, anti-predator defenses, and seasonality in this community.

45-6 Szejner-Sigal, A*; Williams, CM; University of California, Berkeley; *aszejner@berkeley.edu*

The more the lazier: Overwintering aggregations reduce energy use in the ladybird beetle Hippodamia convergens

Energy conservation is tightly linked to the survival and fitness of overwintering ectotherms. To survive winter, many ectotherms enter diapause, a genetically programmed state of metabolic suppression. Most ectotherms diapause individually in sheltered hibernacula, however some form aggregations with conspecifics during winter. Aggregations are often associated with thermal buffering and water conservation, but the effect of aggregations on metabolic rates and energy use remains largely underexplored. The convergent ladybird beetle (*Hippodamia convergens*) occurs across North America and overwinters in large aggregations, making it a great candidate for testing the effect of aggregation size on metabolic rates in overwintering ectotherms. We measured metabolic rates of beetle aggregations of 1, 10, 25, and 50 individuals using stop-flow respirometry across two ecologically relevant temperatures. We tracked locomotor activity across aggregation sizes and temperatures to assess the role of activity and

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temperature in driving group effects on metabolic rate. Metabolic rates decreased with increasing aggregation size at both temperatures, but the decrease was steeper at lower temperature. Activity decreased with aggregation size, but only at low temperatures. These results suggest that individuals within aggregations enter a deeper metabolically inactive state that single beetles cannot achieve. This energy saving strategy may result from the aggregations' boosted aposematic signal and thermohygric buffering, while single beetles face higher risks of predation and abiotic stress. This novel strategy for energy conservation may be an additional selective advantage for the evolution of large overwintering aggregations.

S10-4 Takagi, D; University of Hawaii; *dtakagi@hawaii.edu*
Acrobatic maneuvers of larval copepods
Larval copepods are microscopic crustaceans constrained by strong viscous forces in water. Swimming and maneuvering in three dimensions require a careful coordination of the appendages and the tail. High-speed videos reveal intriguing kinematics, consisting of asynchronous beating in a metachronal rhythm. Mathematical modeling elucidates the basic physical mechanisms underlying the locomotion and rotation with stiff body parts, which could be readily implemented in robotics and engineering applications. I will present an overview of the recent experimental and theoretical findings.

S4-6 Takara, C*; Hu, A; Sathish, T; Takara, E; Tejada, I; Medina-Sanchez, P; Chavez-Melendez, J; Guerrero-Campos, A; Haile, M; Chappell, C; Okada Design, Cupertino, CA and Xinampa Bio, Salinas, CA, Stanford University, Stanford,CA; *corinne@okadadesign.com*
BioJam Camp, bioexplorations driven by community connections
BioJam Camp explores ways to engage teens through their own creativity and culture in bioengineering and biomaterial design as pathways for them to connect their communities to biodesign conversations. This summer camp (which extends into the school year with teen designed community workshops), creates a framework for science education that is collaboratively designed with under-served teens using a framing that is mindful of equity, access, and

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anchored in culture. The 2020 camp was conducted as a virtual camp centered around physical kits delivered to the teens. https://biojamcamp.weebly.com/ https://biojamcamp.weebly.com/kit-contents.html

45-8 Talal, S*; Cease, AJ; Harrison, JF; Arizona State University, Tempe, Arizona; *stav.talal@gmail.com*

High carbohydrate diets result in respiratory exchange ratios above 1 and increased lipid synthesis in locusts

Respiratory exchange ratios (RER, CO_2 production divided by oxygen consumption) range from 0.7 (fats) to 1 (carbohydrates) depending on fuels used for catabolism. Elevation of RER above 1 has been previously observed, and this has been proposed to be due to either synthesis of lipid from carbohydrate or catabolism of carbohydrate via the pentose phosphate pathway to augment glutathione (antioxidant) production. We measured RER and lipid synthesis in late-instar South American locusts (*Schistocerca cancellata) fed on artificial diets varying in protein:carbohydrate (p:c) ratio for 3-5 days. In both outbreaking field populations in Paraguay and the Arizona lab colony, when removed directly from food, RER values increased as the p:c content of the diet decreased, reaching 1.2 on the lowest p:c diet. Lipid synthesis also increased linearly as p:c decreased, and theoretical calculations suggest that lipid synthesis can account for the observed elevations in RER. Surprisingly, when RER was measured for nymphs while feeding, values were always 1. Our results strongly support the hypothesis that in locusts, RER above 1 can result from lipid synthesis from carbohydrates occurring after cessation of feeding on high carbohydrate diets. This research was supported by NSF IOS-1826848 and BARD FI-575-18.*

62-1 Talbott, KT*; Soini, HO; Novotny, MV; Ketterson, ED; Department of Biology, Indiana University, Bloomington, IN, Institute for Pheromone Research, Indiana University, Bloomington, IN; *kmtalbot@iu.edu*

Does female songbird odor vary by blood parasite identity or parasite load?

Variation in individual odor has become an active area of study in songbird ecology. What factors influence odor variation, and what information might such variation convey to potential receivers? For female dark-eyed juncos (*Junco hyemalis hyemalis*) in the early spring, conspecifics and vectors of disease are potential receivers assessing individual odor. We asked whether overall odor composition (that is, the relative proportions of volatile compounds found in junco preen oil) varies significantly between juncos naturally infected with malaria-causing haemosporidian

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parasites and uninfected juncos. Preliminary results suggest no significant relationship between host odor and the presence of haemosporidian infection. However, haemosporidian genera vary in transmission ecology as well as host virulence. Therefore, we focused further inquiry on the relationship between mosquito-borne *Plasmodium* parasites and host odor, as *Plasmodium* often causes greater impacts on songbird fitness compared to other haemosporidian genera. Therefore, we asked whether odor composition varies between uninfected and *Plasmodium*-infected juncos. In addition, we asked whether odor composition varied with parasite load in infected birds, which we predicted to be the case if host metabolic pathways influencing odor are impacted by parasitism in a dose-dependent manner. We will discuss our findings in the context of volatile cues known to be detectable by *Plasmodium* vectors as well as host conspecifics.

50-9 Tamvacakis, AN*; Ozment, ET; Nakanishi, N; University of Arkansas, Fayetteville; *tamvacakis@gmail.com*

The transcription factor POU-IV is required for mechanoreceptor cell differentiation and touch-response behavior in the sea anemone Nematostella

The ability to sense mechanical stimuli is crucial for survival, but do disparate animal species share similar mechanisms for mechanoreceptor cell development and mechanosensation? Amongst vertebrates, a cell type known as a hair cell transduces certain mechanical stimuli through movement of stereocilia. The evolutionarily conserved transcription factor POU-IV (Brn3) is required in mammals for both embryonic hair cell stereocilia formation and adult mechanosensation. The sea anemone *Nematostella vectensis* is a member of Cnidaria, a sister group to Bilateria. Its tentacles respond to mechanical stimuli and contain a stereocilia-bearing cell type which is morphologically similar to vertebrate hair cells. However, whether cnidarian hair cells share developmental, functional, or genetic features with vertebrate hair cells was unclear. We found that *Nematostella* hair cells expressed POU-IV. We established a POU-IV CRISPR knockout line, and found that knockout animals lacked stereociliary rootlets. Knockout animals were significantly less responsive to mechanical stimuli compared with non-mutant littermates. A preliminary comparison of

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published transcriptomes from POU-IV mutants and specific cell populations revealed that differential expression of several vertebrate hair cell gene homologues correlated with presence of POU-IV and hair cells. Thus, there was a correlation between POU-IV expression, specific cell type morphology, gene expression, and mechanosensory behavior. The presence of shared features between cnidarian and vertebrate hair cells sheds light on a means by which an evolutionarily conserved transcription factor can affect sensory ability across distantly related species.

2-1 Tan, KP*; Degnan, SM; Conaco, CG; Marine Science Institute, University of the Philippines, Quezon City, Philippines, School of Biological Sciences, University of Queensland, Australia; *kptan@msi.upd.edu.ph*

Neuroendocrine regulation of the metamorphic transition in the giant clam, Hippopus hippopus

Metamorphosis is a common developmental strategy within the animal kingdom. In marine invertebrates, this is characterized by a habitat shift from the pelagic into the benthos, accompanied by dramatic morphological, physiological, behavioral, and ecological changes in the metamorphosing larvae. Studies on some commercially cultured molluscan species have demonstrated the significant role played by neuronal and neuroendocrine signaling in the regulation of this process. However, it is still unclear how external and internal messages translate into the complex morphogenetic processes observed during this key developmental transition. In this study, we identified molecular targets crucial in the metamorphosis of the giant clam, *Hippopus hippopus*, an economically important but vulnerable species, by using comparative transcriptomics and pharmacological assays. We identified neuroendocrine-related genes expressed in the non-competent larvae, competent larvae, and metamorphosed juveniles, and described their gene expression patterns over the course of metamorphosis. Our results also revealed the potential role of neuroactive chemicals, such as GABA, serotonin, epinephrine, and L-DOPA, in *H. hippopus* metamorphosis. In particular, epinephrine effectively induced settlement and triggered faster metamorphosis in the giant clam. Findings from this study will aid in the development of protocols for effective settlement induction in cultured giant

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clams and contribute to a more comprehensive understanding of the molecular pathways governing molluscan metamorphosis.

2-8 Tanner, RL*; Bowie, RCK; Wang-Claypool, C; Stillman, JH; University of California, Davis, University of California, Berkeley, University of California, Berkeley; San Francisco State University; *rltanner@ucdavis.edu*

High thermal tolerance, but not its plasticity, driven by habitat temperature and genotype in an intertidal sea hare

Local variation in microclimate, with extreme events amplified by ongoing climate change, can drive divergent physiological responses to warming across populations. As habitat temperature characteristics shift with climate change, populations may be required to use plasticity to deal with rapid shifts in thermal extremes. Applying a population genomics approach (RADseq), we investigated heat tolerance and metabolic rate in the direct-developing sea hare, *Phyllaplysia taylori*, to determine whether short-term plasticity was influenced by differences in microclimate. Using this method, we identified possible correlations between thermal tolerance phenotype and genotype in *P. taylori* collected from sites along the western US coast from Ocean Shores, WA to Morro Bay, CA, that were acclimated to winter, summer, and future summer temperatures. *P. taylori* from all locations consistently exhibited critical thermal maxima (CT_{max}) above habitat temperatures, even when average daily variation in habitat temperature was considered (CT_{max} ranged from 24-35°C, average=30.1±0.2°C; average habitat temperature ranged from 12-20°C, average=21±0.8°C). CT_{max} and compensatory metabolic suppression after heat stress were correlated to habitat temperature, whereas only metabolic suppression was correlated with genetic structure. The breadth of plastic responses we observed (11°C) was substantially wider than reported for other poikilothermic taxa in the literature and did not appear to be population-specific. Our findings suggest that high plasticity of thermal tolerance precedes local adaptation, and improves the physiological resilience of populations under climate change.

44-9 Tao, CY*; Cohen, RE; Minnesota State University,

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A breeding-like transition occurs prior to changes in environmental conditions in a lizard species

Seasonally breeding animals, such as the green anole lizard (*Anolis carolinensis*), differ morphologically, physiologically and behaviorally between their breeding and non-breeding states. While non-breeding, anoles have regressed gonads, lower gonadal steroid hormone levels and decreased reproductive behavior compared to breeding lizards. Initially, non-breeding anoles enter a refractory period where reproduction is inhibited. After, a post-refractory period occurs where breeding can be triggered by appropriate environmental conditions. However, it remains unclear what morphological, molecular and behavioral parameters might differ across these two non-breeding periods. To address this, male anoles were examined during October (refractory) and early February (post-refractory), while visually isolated and maintained in the laboratory under the same non-breeding-like environmental conditions. Preliminary results revealed that post-refractory testes had a greater mass, greater volume, and whiter color (all $p < 0.01$, $n = 8$) compared to refractory testes. Interestingly, these results suggest that, independent of breeding-like environment conditions, time-dependent physiological changes are occurring that initiate the transition towards breeding. We are continuing to conduct analyses on reproductive behavior, gonadal and kidney morphology, as well as gonadal gene expression in these lizards to characterize any additional differences between refractory and post-refractory periods. In our study, we have seen that environmental stimulation is not necessary for the transition to a breeding-like state in this species. However, this raises questions regarding what potential molecular and/or physiological factors, independent of external cues, are required for the onset of breeding.

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91-4 Tardelli Canedo, P*; Baker, CM; Morisawa, R; Pessereau, EJ; Boyer, SL; Macalester College, Saint Paul, MN, Harvard University, Cambridge, MA; *ptcanedo@gmail.com*

A tale of two morphs: Phylogeography of Neopurcellia salmoni, with the first report of male polymorphism in the harvestman suborder Cyphophthalmi

Neopurcellia salmoni is a mite harvestman found throughout the forests of the west coast of New Zealand's South Island. This species range is unusually large for the notoriously dispersal-limited Cyphophthalmi, raising the possibility of multiple cryptic species within the lineage. In order to test this hypothesis, we used scanning electron microscopy to examine a large number of individuals from throughout its range, and discovered two distinct male morphotypes distinguished by the presence or absence of dorsal glandular pores. We performed phylogeographic and population genetic analyses using DNA sequence data from the fast-evolving mitochondrial locus COI. Tree topologies revealed two well-supported clades within *Neopurcellia* occupying non-overlapping geographical regions of the west coast. The strong correlation between the evolutionary relationships of lineages within *Neopurcellia* and the geographic distribution of its populations indicates isolation by distance, as expected with dispersal-limited organisms; population genetic analyses confirm strong isolation of populations. However, we discovered that the distribution of male morphotypes does not follow any geographic or phylogenetic pattern. While the presence of two different morphotypes initially suggested multiple *Neopurcellia* species, phylogeographic analysis allowed us to reject this hypothesis. We therefore report here the first known case of male polymorphism in the suborder Cyphophthalmi.

S3-12 Taylor, JRA*; Lowder, K; deVries, M; University of California, San Diego, NOAA, San Jose State University; *j3taylor@ucsd.edu*

Exoskeleton weapons and defenses in crustacean conflicts

Contests in the crustacean world are fought with a range of exoskeletal weapons, including crab claws, mantis shrimp raptorial appendages, shrimp rostrums, and lobster antennae. When used with effective fighting behavior, the quality of these weapons can determine the winners of contests. Consequently, weapons are focal in behavioral and biomechanical research, with defenses being important, but less studied. The challenges of studying the biomechanics of dynamic fighting behavior have led to simplified assessments of weapon and defense capabilities that do not necessarily reflect their use in natural contests. A holistic

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approach would provide a deeper understanding of these complex interactions. First, weapons and defense structures should be examined as whole structures and with appropriate mechanical tests. Cuticle has been examined extensively for its contributing properties, but the construction and mechanical behavior of the whole structure is more functionally relevant. Using appropriate mechanical tests and finite element modeling that mimic how the structure is used during contests would reveal how structures function in fighting behavior. Second, applying technologies to measure in vivo forces during conflicts could reveal a more realistic use and matching of weapons and defenses. Currently, most studies focus on maximum forces produced or resisted, which do not necessarily reflect the forces exchanged during fights. Lastly, assessing the effects of environmental conditions on weapon and defense architecture is important, because construction of the exoskeleton is demonstrably responsive to parameters such as ocean pH, temperature, pollutants, etc. Environmental conditions may affect the biomechanics of weapons and defenses in ways that influence contest behavior and outcomes.

71-2 Taylor-Burt, KR*; Biewener, AA; Franklin & Marshall C, Harvard U; *kairit03@gmail.com*

Hindlimb skeletal anatomy and kinematics vary with swimming behavior in ducks

Hindlimb swimming has evolved several times in birds. However, swimming ability can come at a cost to terrestrial locomotion. Ducks have a range of swimming behaviors, including highly terrestrial species, surface swimmers, and divers. We explored how swimming behavior in ducks relates (1) to hindlimb and pelvic skeletal anatomy across the duck tree and (2) to kinematics during walking, surface swimming, and diving in representative species. We hypothesized that (1) hindlimb and pelvic anatomy of diving ducks would resemble hindlimb swimming specialists like grebes and loons while terrestrial and surface swimming species would resemble galliformes and other non-swimming birds and (2) differences in surface swimming and diving ducks' kinematics would indicate a tradeoff between diving and walking abilities. While ducks do show differences in hindlimb skeletal anatomy among behavioral groups, only one of the measured traits (lateral cnemial crest size)

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exhibits the hypothesized pattern, with divers exhibiting larger lateral cnemial crests than surface swimmers and terrestrial species, a structure that is thought to contribute to swimming ability in loons and grebes. Some observed kinematic patterns may indicate advantages in swimming (i.e., faster swimming velocities and longer stride lengths) and greater costs in terrestrial locomotion (i.e., higher body angle and higher stride frequency) for the diving specialists relative to the surface swimmers. Surprisingly all species performed similarly across behaviors. Hindlimb anatomy and kinematics show some variation with swimming ability in closely related species, which may reflect the demands that swimming places on the body. However, that all three species use similar top walking velocities and are capable of diving highlights the versatility of the duck body plan.

46-3 Teets, NM*; Spacht, DE; Potts, LJ; Gantz, JD; Lee, RE; Denlinger, DL; University of Kentucky, Lexington, Ohio State University, Columbus, Hendrix College, Conway, Miami University, Oxford; *n.teets@uky.edu*

Microhabitat diversity influences physiology and phenology in an Antarctic insect

The midge *Belgica antarctica* is Antarctica's only endemic insect and occupies diverse habitats with considerable variation in vegetation, hygric conditions, and temperature. However, the extent to which microhabitat diversity influences fine-scale distribution, physiology, and phenology has not been assessed. To identify ecological drivers of population density, we measured arthropod abundance and microhabitat conditions across five islands. Across plots, midge abundance was highly variable (0-40,000 larvae m^{-2}), and models that included both abiotic and biotic features of the microhabitat best explained this variation. There were few strong predictors of density, but midges tended to be associated with terrestrial algae. In a subsequent study, we assessed the extent to which microhabitat diversity influences phenology and metabolic physiology in five midge populations. Despite the proximity of these habitats (four were on the same island within one hectare), there were considerable differences in thermal conditions, with average temperature differing more than 2° C between the warmest and coolest location. These environmental differences corresponded

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with physiological differences, as seasonal changes in size, metabolic rate, and biochemical composition were site-specific. There were also significant differences in phenology across sites, indicating that fine-scale microhabitat variation could lead to reduced gene flow between temporally isolated populations. Together, these results indicate that fine-scale environmental characteristics strongly influence the distribution and physiology of midges and should be accounted for when predicting responses to environmental change.

5-7 TerMarsch, H; Ward, JL*; Ball State University, Muncie, IN; *ward@bsu.edu*

Mechanosensory signaling during reproductive interactions in fishes

Fishes present a unique opportunity to investigate hypotheses related to multimodal communication. Conspecific social interactions in fish are characterized by visual aggressive and courtship displays that involve directed movements of the body and fins, resulting in the local displacement of the surrounding water. Because fish are able to perceive near-field hydrodynamic features of the physical environment via the lateral line system, these body-generated hydrodynamic flows have the potential to function as mechanosensory signals that assist receivers in making appropriate behavioral decisions. Here, we tested the hypothesis that mechanosensory signals generated by male fish during courtship influence female mate choice decisions. We manipulated the ability of female fathead minnows, *Pimephales promelas*, to detect changes in water flow via the lateral line system and conducted choice tests to determine whether females with and without access to mechanosensory information differed in patterns of mate discrimination. In dual-choice assays, female minnows without access to mechanosensory information from courting males showed reduced mate discrimination compared to control females, and reduced reliance on male courtship as a criterion of choice. These data add new insight into the role of body-generated hydrodynamic flows as social signals and extend our limited understanding of the role of the lateral line system as a channel of intraspecific communication.

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24-6 Thandiackal, R; White, C; Bart-Smith, H; Lauder, G*; Harvard University, Univ. of Virginia; *glauder@gmail.com*

Tuna robotics: measuring body pressure, thrust forces, and work during linear acceleration

Fish routinely accelerate during locomotor maneuvers, and yet little is known about the dynamics of acceleration performance. In order to better understand how fish accelerate, we used a robotic model inspired by tuna to generate linear accelerations of various magnitudes and then quantified body kinematics, surface pressures, thrust forces and work along the body length. The Tunabot Flex platform is propelled by a 12V DC motor, measures 25.5 cm in total length, has yellowfin tuna-like body and tail profiles, and contains three body joints in addition to a fourth peduncle joint that allows bending. Linear accelerations of various magnitudes in which the tunabot moved rapidly forward were initiated in still water from a stretched-straight body position at zero initial velocity. Particle image velocimetry with high-speed video at 2000 fps was used to quantify body kinematics and fluid flow patterns, and we measured electrical power consumption throughout the maneuver. Linear accelerations varied from 0.7 m/s^2 to 3.5 m/s^2 with body kinematics similar to previous results from accelerating fishes. Peak accelerations resulted in a strong thrust wake with maximum velocities over 1 m/s. Electrical power consumption peaked within 10 ms of initiating acceleration while total mechanical power and resulting thrust force reached their initial maxima at 100 ms. The head region generated net drag, while thrust was provided by posterior body segments and the tail. Studying fish acceleration performance in an experimental platform where electrical power input, body kinematics, flow visualization, and power output into the fluid can all be simultaneously measured provides a new opportunity to understand unsteady locomotor behaviors in both fishes and bio-inspired aquatic robotic systems.

18-8 Thandiackal, R*; Lauder, GV; Harvard University; *rthandiackal@fas.harvard.edu*

Swimming in thrust wakes: implications for fish schooling dynamics

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It has long been hypothesized that schooling in fish is linked to hydrodynamic advantages. Past studies have found that trailing individuals exhibit reduced tail beat frequencies and that they consume less energy at those trailing positions. Together with previous work on computational simulations these studies on live fish demonstrate energetic benefits of swimming in schools. Most research has focused on the benefits of swimming in reduced velocity (drag) wakes shed by pairs of upstream fish but wakes inside fish schools also include regions with higher mean flow (thrust wakes) than in the free stream. Here we investigate the effects of thrust wakes on fish swimming behavior using an experimental approach and quantify the locations chosen by swimming downstream fish. We emulated fish-like thrust wakes using a mechanical flapper, which allowed us to generate an inverse Karman vortex street and increased mean flow speed occurring at fish-like Strouhal numbers between 0.2 and 0.4. We then recorded the movements of fish swimming in these fish-like wakes and collected data that includes 1) longer term fish position and midline kinematics of fish swimming under these conditions for different flow speeds captured over 20-30 minutes each, and 2) flow field visualizations using particle image velocimetry in the most frequently observed swimming positions. These experiments are expected to reveal both preferred swimming positions in thrust wakes and to provide a better understanding of the underlying hydrodynamic mechanisms in fish schools.

1-12 Thawley, CJ*; Kolbe, JJ; Neumann University, University of Rhode Island; *thawleyc@neumann.edu*

Seeing lizards in a new light: How does artificial light at night impact anoles?

As urbanization accelerates globally, the impacts of artificial light at night (ALAN) on a variety of species are increasing. While negative impacts of ALAN have been documented in many taxa, little is known about the effects of ALAN on lizards. Many lizard species thrive in urban habitats, and both nocturnal and diurnal lizards are known to exploit the "night-light niche." While these species may benefit from increased opportunities created by artificial light sources, few studies have quantified impacts of ecologically-relevant levels of ALAN on lizards in the lab or field. Anoles are

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diurnal lizards amenable to lab and field studies that manipulate ALAN. An established body of research on anole physiology, behavior, natural history, and ecology make them an ideal group in which to investigate the effects of ALAN. In a variety of field and lab experiments, we have found some anticipated negative consequences of ALAN on anoles as well as unexpected positive effects. Anoles exposed to ALAN were warier at night and had lower blood glucose and decreased endurance during the day, indicating potential costs to exposure. However, anoles did not avoid ALAN and in some cases were able to exploit ALAN to capture prey. Anoles exposed to ALAN in the lab reproduced earlier in the spring and experienced higher growth and reproduction without concomitant increases in corticosterone, suggesting that they might achieve higher fitness in the presence of ALAN. Intriguingly, many species of anoles which utilize ALAN are also successful invaders and exploiters of urban areas. Taken together this evidence suggests that future work should examine whether the ability to tolerate or benefit from ALAN may be an important filter determining which species occupy urban environments or successfully invade novel human-impacted habitats.

21-3 Thomas, JT*; Spady, BL; Munday, PL; Watson, S-A; James Cook University, Townsville, Queensland, Australia, Museum of Tropical Queensland, Townsville, Australia; *jodi.thomas@my.jcu.edu.au*

The role of ionotropic receptors in behavioural alterations at elevated CO2 in a cephalopod

Projected future CO_2 levels in the ocean can alter the behaviour of marine animals. Disrupted functioning of the γ-aminobutyric acid type A ($GABA_A$) receptor is suggested to underlie CO_2-induced behavioural changes in fish, however, the mechanisms underlying behavioural changes of marine invertebrates at elevated CO_2 levels are not well understood. We exposed two-toned pygmy squid *Idiosepius pygmaeus* to ambient (~450 µatm) or elevated (~1,000 µatm) CO_2 levels for seven days. Squid were treated with sham, gabazine ($GABA_A$ receptor antagonist) or picrotoxin (chloride (Cl^-) channel blocker) immediately before measurement of conspecific-directed behaviours and activity levels upon mirror exposure. If disrupted function of $GABA_A$-like and/or other Cl^- channel receptors underlies the behavioural changes, we

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predicted that gabazine and picrotoxin would attenuate the behavioural changes at elevated CO_2. Elevated CO_2 increased squid activity levels and altered some, but had no meaningful effect on other, conspecific-directed behaviours. Gabazine and picrotoxin attenuated some of the behavioural changes at elevated CO_2, indicating altered $GABA_A$-like and Cl^- channel receptor functioning may underlie these behavioural changes. However, gabazine and picrotoxin had the same effect at both CO_2 levels on other behavioural traits, suggesting altered function of $GABA_A$-like and Cl^- channel receptors was not responsible for other behavioural changes at elevated CO_2. Our results suggest multiple mechanisms may be involved, which could explain variability in the effects of CO_2 and drug treatment across behaviours.

95-8 Thomas, KN*; Gower, DJ; Streicher, JW; Bell, RC; Fujita, MK; Schott, RK; Douglas, RH; The Natural History Museum, London, California Academy of Sciences, San Francisco, CA and National Museum of Natural History, Smithsonian Institution, Washington DC, The University of Texas at Arlington, York University, Toronto, City, University of London; *kate.thomas@nhm.ac.uk*

Ocular transmission across frog and toad diversity

Frogs and toads (Amphibia: Anura) exhibit high ecological and behavioral diversity, and species adapted to diverse habitats and lifestyles likely have different visual priorities. One way that eyes vary across species and ecology is in the spectral transmission of the lens. Light from the environment must pass through the ocular media of an eye before it reaches the retina. Animal lenses are typically transparent at longer wavelengths of the visible spectrum, but some lenses have pigments that absorb short wavelengths before they reach the retina. While this precludes sensitivity to UV light and reduces absolute sensitivity, it can protect the retina from UV damage and improve spatial acuity by reducing chromatic aberration and Rayleigh scatter. Anurans are known to show variation in the short-wavelength transmission of lenses across some species; however, ecological correlates and causes of these patterns are unclear. We measured spectral transmission (300-700nm) of lenses from 129 individuals belonging to 89 anuran species with diverse lifestyles. We then used phylogenetic comparative methods to test for correlations between

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short-wavelength transmission and adult habitat, reproductive ecology, and activity pattern. We discuss the role ecology may play in driving the evolution of ocular transmission in anurans, and how amphibians compare to other vertebrates.

50-3 Thompson, AW*; Wojtas, H; Davoll, M; Braasch, I; Michigan State University, East Lansing, MI, Clemson University, Clemson, SC; *thom1524@msu.edu*

The genome of the bi-annual Rio pearlfish (Nematolebias whitei) informs the genetic regulation of diapause and environmentally-cued hatching in extreme environments

Annual killifishes are emerging eco-evolutionary developmental models due to their unique embryonic dormancy used to study development, metabolism, aging, and stress tolerance in vertebrates. They inhabit seasonal pools that desiccate, resulting in the death of the adult population. Unique adaptations including specialized egg structures and up to three diapauses that slow developmental and metabolic rates enable the embryonic population to survive dry seasons in the soil. When the habitat floods, annual killifish terminate their third diapause (DIII), hatch, and begin a new lifecycle. We sequenced the genome of the bi-annual Rio pearlfish, *Nematolebias whitei*. Rio pearlfish are native to seasonal pools in the coastal plains near Rio de Janeiro, Brazil, where they complete two life cycles per year. During DIII, pearlfish have fully developed, functioning organ systems when making changes to metabolism and cell cycle during developmental arrest. Our model species represents an independent origin of seasonality, different from other killifish species. DIII is tightly linked with expression of a complex family of hatching enzymes, and our analysis of these enzymes, including those of pearlfish, reveals a complex evolutionary history of hatching enzymes in killifishes. Additionally, we use the pearlfish to develop Killi-Kits as an educational outreach tool. Killi-Kits include dormant killifish eggs, a small tank, food, a clip-on smartphone microscope, and instructional online resources. A-FISH-ionados of all ages can observe killifish development with the smartphone microscope. Overall, we establish the Rio pearlfish as a novel research organism and educational toolkit for Extremo-Evo-Devo.

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75-8 Thompson, NE*; Rubinstein, D; Parrella-O'Donnell, W; Brett, M; Demes, B; Larson, SG; O'Neill, MC; NYIT College of Osteopathic Medicine, Lancaster General Hospital, Stony Brook University, Midwestern University; *nthomp03@nyit.edu*

A reduced 'pelvic step' partially explains short stride length during human bipedalism

Humans walk with relatively short strides when compared to other facultatively bipedal primates walking at the same dimensionless speed. However, the kinematic basis of this difference is unclear. Differences in non-sagittal plane pelvic motion may contribute to it, but to an unknown extent. While humans use small transverse-plane pelvic rotations during walking, the pelvic rotations of facultative bipeds are two to three times larger. Pelvic rotations contribute to anterior translation of the swing-side lower limb, thereby increasing bipedal stride length ('the pelvic step'). Here, we determine the contribution of the 'pelvic step' to stride length in human and chimpanzee bipedal walking. Kinematic data were recorded over a wide speed range for humans (0.3 ms-1-2.0 ms-1) in order to match a range of self-selected speeds of bipedal chimpanzees. At similar dimensionless speeds, humans have dimensionless strides that are 20-30% shorter than those of bipedal chimpanzees, and a pelvic step that is 5-6 times smaller than that of bipedal chimpanzees. Smaller pelvic rotation magnitude in the transverse plane in humans accounts for a third (25-37%) of the difference in dimensionless stride length between human and bipedal chimpanzee walking. Reduced pelvic rotations may engender a decrease in cost of locomotion via reductions in overall body angular momentum, which likely outweighs the increase in stride length that results from a non-human-like pelvic step. These results suggest a constraint to lengthening strides in humans and likely early hominins. Funded by NSF grants SBE 0935321, SMA 1719432, and the Leakey Foundation.

95-12 Tidswell, BK*; Tytell, ED; Tufts University; *ben.tidswell@tufts.edu*

The role of vision and flow sensing in the schooling behavior of giant danios

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Fish and other organisms move together in coordinated groups to defend against predators, give them allies to help gather food, and lessen the metabolic costs of transportation. Whether they are in a herd, flock, or school, animals form and maintain their groupings using multiple sensory modalities. In the lab, animal groups are often studied in well-lit, open environments, when their senses receive good information. But in the natural environment, sensing is often limited. For example, fish school in darkness, flow, or turbulence, conditions that limit the information they can gain from their senses. Our research investigates how the school structure of giant danios (*Devario aequipinnatus*) changes in conditions that limit sensory information. The goal of this work is to understand how fish adjust their schooling behavior in order to adapt to information-poor situations. We placed giant danios in a flow tank and varied the light level and flow speed, then tracked their midlines using DeepLabCut. Using this data we analyze the relationship between the relative position of fish in the school and the cross-correlation of their midline curvatures. This cross-correlation is a measure of synchronization in the movements of the fish. We quantify how this synchronization relates to school structure, and how it changes under the different sensory conditions. This research is our first step investigating how the information fish have about each other affects their ability to avoid predators and school effectively when they have limited information about the world around them.

39-4 Tingle, JL*; Garland, T; University of California, Riverside; *jessica.tingle@email.ucr.edu*

Morphological evolution in relation to sidewinding, arboreality, and precipitation in snakes of the family Viperidae

Compared with other squamates, snakes have received relatively little ecomorphological investigation. We examined morphometric and meristic characters of vipers, in which both sidewinding locomotion and arboreality have evolved multiple times. We used phylogenetic comparative methods that account for intraspecific variation (measurement error models) to determine how morphology varied in relation to body size, sidewinding, arboreality, and precipitation. Some traits scaled isometrically; however, tail length was positively allometric and head dimensions were negatively

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allometric. Although we expected sidewinding specialists to have different body proportions and more vertebrae than non-sidewinding species, they did not differ significantly for any trait after correction for multiple comparisons. This result suggests that mechanisms enabling sidewinding involve musculoskeletal morphology and/or motor control, that viper morphology is inherently conducive to sidewinding ("preadapted"), or that behavior has evolved faster than morphology. With body size as a covariate, arboreal vipers had long tails, narrow bodies, and lateral compression, consistent with previous findings for other arboreal snakes, plus reduced posterior body tapering. Species from wetter environments tended to be larger, with longer heads and reduced anterior tapering. This study adds to the growing evidence that, despite superficial simplicity, snakes have evolved various morphological specializations in relation to behavior and ecology.

43-2 Titon, SCM*; Titon Jr, B; Gomes, FR; Assis, VR; University of Sao Paulo, Sao Paulo, Brazil; *stefannychristie@gmail.com*

Short-term stressors and corticosterone treatment effects on toad's immunity

In recent years it is growing the idea that stress-induced immunomodulation is bimodal: with acute stress associated with enhancing effects while chronic stress with suppressive effects. However, the immune-endocrine interactions and its implications are often overlooked in amphibians. We investigated the effects of corticosterone (CORT) treatment and short-term stressors on CORT plasma levels and the immunity of toads (*Rhinella icterica*), using distinct protocols: restraint, immune challenge (with lipopolysaccharide, LPS), and CORT transdermal application (TA). Our results showed increased CORT and neutrophil: lymphocyte ratio (NLR) regardless of the stress input. While the bacterial killing ability (BKA) was not affected by any treatment, suggesting this immune parameter might be a more constitutive and robust response. The cellular immune response showed distinct patterns. Increased phagocytosis of blood leukocytes and phytohemagglutinin edema following LPS and CORT TA (15ug), respectively. In contrast, the phagocytosis of peritoneal leukocytes decreased after CORT TA (1 and 10ug). Together these results signalize the local immune function, but not the systemic immune function, might be impaired

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by acute increases in CORT. Although such differences in cellular immunity might be linked to distinct CORT doses or the interaction between CORT and other immune mediators. Overall, our results highlight the relevance of investigating distinct contexts for CORT increase (physiological and pharmacological), arising from different situations (CORT treatment and acute stressors), as well as diverse immune components (local and systemic, cellular and protein) for a better understanding of the stress-induced immunomodulation.

27-8 Tituskin, JR*; Waddell, SM; Mabry, KE; New Mexico State University, University of California, Davis; *tituskinjuliar@gmail.com*

Species-specific responses to warming alter community composition of California dragonflies

Species are responding to global climate change in varied and nuanced ways. However, how species-specific responses affect interactions among species remains poorly understood. It is important to understand species interactions under potential climate change scenarios because those interactions can in turn alter community dynamics. We conducted two complementary experiments to examine how simulated warming might alter intraguild predation (IGP) rates and resulting adult assemblage composition in three species of North American dragonflies: *Pachydiplax longipennis*, *Plathemis lydia*, and *Libellula luctuosa*. First, using both *P. longipennis* and *L. luctuosa*, we isolated inter- and intraspecific pairs of larval dragonflies of different size differentials to determine how size and species identity might influence IGP rates. In tandem, we conducted a year-long mesocosm experiment with all three species to assess how simulated warming and heat waves influenced the resulting adult dragonfly assemblages. Our IGP trials revealed that *P. longipennis* individuals were much more likely to engage in IGP than *L. luctuosa*, regardless of size differential. In the mesocosm experiment, emerging adult assemblages were dominated by *P. longipennis* individuals, a pattern that was most pronounced in the control treatment. Our results indicate that while *P. longipennis* may be the competitively dominant species under current

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ambient conditions, warming may alter this dynamic and lessen the dominance of this species on resulting assemblage composition.

62-10 Torres-Sánchez, M*; McGrath-Blaser, S; Villate, J; Longo, AV; University of Florida, Department of Biology, Gainesville, FL 326011; *mtorressanchez@ufl.edu*

Chytrid fungi transcriptomic signatures indicate different infection strategies in newts

The chytrid fungi *Batrachochytrium dendrobatidis* (*Bd*) and *Batrachochytrium salamandrivorans* (*Bsal*) are two of the most relevant pathogens in vertebrates due to their broad host range and their devastating effects on amphibians. However, we know little about the functional processes driving the invasion dynamics and disease outcome across hosts, and much less between single pathogen infections and coinfections. Here, we used publicly available RNA-seq data to find evidence of different infection strategies. We analyzed the transcripts from the skin of two species of newts (*Notophthalmus viridescens* and *Tylototriton wenxianensis*) singly infected with one or the other fungal pathogen, the transcripts from the skin of *N. viridescens* coinfected with both fungi, and performed four differential gene expression analyses: (i) *Bd* and (ii) *Bsal* expression between *N. viridescens* and *T. wenxianensis*, and (iii) *Bd* and (iv) *Bsal* expression between single and co-infection in *N. viridescens*. Overall, we uncovered distinct invasion strategies with significant changes in the fungal genetic machinery that is used to infect hosts. We also documented variation in the patterns of gene expression in coinfections that might be related to ecological competition between fungi. Many differentially expressed genes were related to DNA replication and synthesis/modification of proteins. Our findings showed that *Bd* chitin-related genes, which can modify the structural composition of the fungus, shifted their expression levels in coinfections. Finally, we detected expression changes in several genes encoding heat shock proteins, which could reflect hormesis processes (i.e. inhibition, toxicity) as a result of *Bd*-*Bsal* and host-pathogen interactions.

42-7 Torres-Velarde, JM*; Kolora, SRR; Khudyakov, JI; Crocker, DE;

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Sudmant, PH; Vázquez-Medina, JP; University of California, Berkeley, University of the Pacific, Sonoma State University; *torresvelardejulia@gmail.com*

Elephant seal muscle cells adapt to sustained glucocorticoid exposure by shifting their metabolic phenotype

Elephant seals exhibit extreme behaviors characterized by sustained exposure to glucocorticoids, but the mechanisms that allow elephant seals to cope with such conditions remain elusive. We generated a cellular model and conducted transcriptomic, metabolic, imaging, and functional analyses to explore the mechanisms that underlie tolerance to glucocorticoids in elephant seal muscle cells. Elephant seal muscle progenitor cells differentiated into contractile myotubes with a distinctive morphology, gene expression profile, and metabolic phenotype. Exposure to the glucocorticoid dexamethasone at three ascending doses (0.1, 1, and 100uM) for 48h resulted in concerted changes in expression of 6 clusters of genes related to the structural constituents of muscle and pathways associated with energy metabolism and cell survival. Sustained exposure to glucocorticoids also promoted mitochondrial fission, dissociation of mitochondria-ER interactions, reduced oxygen consumption rates (OCR), and a shift of metabolic phenotype towards glycolysis. Knockdown of the glucocorticoid receptor (GR) and downstream expression analyses of catabolic and muscle structural genes corroborated that the observed effects are mediated by GR signaling. Knockdown of the GR-regulated stress gene ddit4 recovered OCR and upregulated genes involved in redox balance. Overall, these results show that adaptation to sustained glucocorticoid exposure in elephant seal muscle cells involves changes the mitochondrial reticulum and mitochondria-ER interactions, which support a reduction in mitochondrial metabolism promoting cell survival.

108-1 Torson, AS*; Roe, AD; Doucet, D; Sinclair, BJ; University of Western Ontario, London, ON, Canada, Natural Resources Canada, Sault Ste. Marie, ON, Canada; *atorson@uwo.ca*

Tissue-specific regulation of diapause in the Asian longhorned beetle, Anoplophora glabripennis

An insect's ability to survive low temperatures throughout winter is critical for range expansion in temperate regions. To cope with

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these stresses, many insects enter diapause, a state of developmental arrest that is concurrent with metabolic suppression and increased cold tolerance. The Asian longhorned beetle, *Anoplophora glabripennis*, is a wood-boring, forest pest species native to China and the Korean peninsula that primarily overwinters as a diapausing prepupae. However, we know little about its overwintering physiology or the mechanisms driving diapause. In this study, we measured tissue-specific changes in gene expression using RNA-seq in lab-reared *A. glabripennis*. We sampled larval fat body, supraesophageal ganglia, midgut, hindgut, and Malpighian tubules during four stages of diapause development: pre-diapause, diapause maintenance, post-diapause quiescence, and post-diapause larval development. We observed distinct tissue-specific gene expression profiles that shifted upon initiation of diapause and again after diapause termination. During diapause *A. glabripennis* upregulate expression of genes involved in the heat shock response, insulin signalling, and epigenetic modification. Tissue-specific characterizations of the diapause phenotype in insects are rare, so these data will aid in increasing the resolution at which we understand the mechanisms governing diapause development in insects.

72-4 Toussaint, SLD*; Youlatos, D; Nyakatura, JA; Institute of Biology and Comparative Zoology, Humboldt University of Berlin, Germany, Department of Zoology, School of Biology, Aristotle University of Thessaloniki, Greece; *severine.toussaint@hu-berlin.de*

Vertical locomotion and associated manual and pedal postures in arboreal mammals

Climbing vertical substrates constitutes an important aspect of arboreal locomotion and many mammals efficiently engage in such behavior despite having different morphologies. Yet, behavioral strategies and locomotor mechanics during vertical ascent or descent are still poorly understood and rarely studied in association with autopodial grasping abilities. Moreover, it is still unclear whether vertical climbing may have played an important role in the evolution of locomotor mechanics in primates (i.e. hindlimb dominance), and in the origin of their specific manual and pedal grasping abilities (i.e. divergent pollex/hallux and nails). We investigated limb mechanics (gait, speed) and

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autopodial grasping postures during ascent and descent on vertical and oblique supports of various diameters (large, medium, small) in 11 primate species (6 strepsirrhines and 5 platyrrhines) and 11 non-primate arboreal species (1 scandentian, 3 rodents, 3 carnivorans and 4 marsupials). Our preliminary results show that primates more often exhibit rump-first descent strategies on vertical substrates, while the other studied mammals preferentially exhibit head-first descents. Also, primates have higher speed during ascents than during descents, unlike other species. Moreover, we found that the use of the pollex and hallux is crucial for ascending small vertical substrates, and interestingly, grasping strategies are more complex during vertical descent, with more particularities across species.

20-1 Touzot, M*; Lefebure, T; Lengagne, T; Secondi, J; Duchamp, C; Mondy, N; Lyon 1 University, CNRS, UMR5023, Villeurbanne, France; *morgane.touzot@univ-lyon1.fr*

Large scale deregulation of gene expression by artificial light at night in the common toads

Artificial Light At Night (ALAN), which dramatically expands worldwide, is considered as a threat to biodiversity. Thus, it is of particular interest to understand how ALAN may affect the day/night cycle gene expression, which could be one of the mechanisms contributing to the harmful physiological and behavioural effects of ALAN on animals. Amphibians, that is the animal group with the worst conservation status, are frequently found in urban and peri-urban wetlands, which are subjected to ALAN. We previously showed that ALAN reduced nocturnal activity and affected breeding behaviour and success of adult toads (*""Bufo bufo""*). Here, we studied, for the first time, gene expression changes in response to ALAN in this species. We first assembled a *""de novo""* transcriptome of *""B. bufo""* tadpoles and then used Illumina RNA-seq to evaluate the transcriptome-wide gene expression response of *""B. bufo""*, experimentally exposed at night, to ecologically relevant light illuminances (control, 0.1 or 5 lux) and sampled at two times (day and night). ALAN affected the day/night cycle gene expression, by reducing the number of differentially expressed genes between day and night and by inducing a day/night cycle expression in non-cyclic genes in

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control conditions. ALAN also affected nocturnal gene expression, in a dose-dependent way, as the expression of 1194 and 3676 genes differed when comparing 0.1and 5 lux, respectively, with control. Moreover, those differentially expressed genes were mainly under-expressed with ALAN. Among the genes affected by ALAN, the majority were involved in immune response, which may affect tadpole's growth and survival.

77-5 Townley, IK*; Rees, BB; Saint George's School, University of New Orleans; *Ian.townley@sgs.org*

Genomic analysis of Actinopterygiian hypoxia-inducible factor alpha reveals "missing ohnologs"

Two rounds of genome duplication (GD) in the ancestor of vertebrates, followed by additional GD during the evolution of ray-finned fishes (Actinopterygii), expanded certain gene families, including those encoding the hypoxia inducible transcription factor (HIF). The present study analyzed Actinopterygian genomes for duplicates of HIFα, the subunit that confers oxygen-dependent gene regulation. In contrast to tetrapod vertebrates that retain three HIFα genes from the ancestral vertebrate GD, four HIFα forms were found in the genomes of primitive Actinopterygians (spotted gar and Asian arowana). All four forms have been retained in zebrafish and related species (Otocephala) and salmonids and their sister taxa (northern pike) but one form (HIF4α) was lost during the evolution of more derived fishes (Neoteleostei). In addition, the current analyses confirm that Otocephala retain duplicates of HIF1α and HIF2α from the teleost-specific GD, provide new evidence of salmonid-specific duplicates of HIF1α, HIF2α, and HIF3α, and reveal a broad distribution of a truncated form of HIF2α in salmonids and Neoteleostei. This study delivers a comprehensive view of HIFα evolution in the ray-finned fishes, highlights the need for a consistent nomenclature, and suggests avenues for future research on this critical transcription factor.

107-2 Toxopeus, J*; Gadey, L; Andaloori, L; Sanaei, M; Ragland, GJ; St. Francis Xavier University, University of Colorado, Denver; *jtoxopeu@stfx.ca*

Costs of averting diapause associated with slow decline of

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metabolic rates at low temperature in the apple maggot fly Rhagoletis pomonella

Diapause, a form of insect dormancy, is thought to facilitate overwintering survival by increasing cold tolerance and decreasing energy drain at high temperatures via metabolic rate suppression. Averting diapause prior to winter is generally assumed to be a lethal phenotype. However, metabolic rate and cold tolerance are plastic - they can change following exposure to different environmental conditions. Here, we tested the hypothesis that cold acclimation can induce a diapause-like phenotype, compensating for the potential costs of averting diapause. We tested this in the apple maggot fly, which exhibits segregating genetic variation for diapause intensity (propensity to avert diapause). This fly overwinters in the soil as a diapause pupa, but can avert diapause (non-diapause) or terminate diapause early (shallow diapause) when reared at warm temperatures. We found that diapause, non-diapause, and shallow diapause pupae were freeze-avoidant and had similar tolerance of extreme low temperatures (cooling to c. −18 ° C) following two months acclimation at 4 ° C. Metabolic rates were higher in non-diapause and shallow diapause than diapause pupae at warm (25 ° C) and cool (4 ° C) temperatures. Non-diapause and shallow diapause metabolic rates decreased slowly over time at 4 ° C, achieving diapause-like metabolic rates. Despite this metabolic flexibility at low temperatures, non-diapause and shallow diapause pupae did not survive prolonged chilling well. We conclude that energy drain at low (not just high) temperatures can contribute to chilling mortality in insects that avert diapause, and cold acclimation can only partially compensate for costs associated with averting diapause.

49-11 Trail, SE*; Salmon, M; Florida Atlantic University; *strail2019@fau.edu*

Evidence for the independent evolution of visual perception during seafinding by hatchling leatherback sea turtles (Dermochelys coriacea)

Newly emerged sea turtle hatchlings use a positive phototaxis at night to locate the ocean from their nest site ("seafinding" orientation). Photic energy is absorbed by dune vegetation but reflected from the ocean surface, providing a reliable intensity

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cue for this response. However, the light wavelengths mediating this response are unknown in leatherbacks (*Dermochelys coriacea*), a critically endangered species. We evoked a phototaxis under lab conditions by presenting hatchlings with near-monochromatic light wavelengths at intensities they would encounter at night. Our goal was to determine if leatherback spectral sensitivities to those wavelengths differed from those of related "hard-shelled" (green turtle, loggerhead) hatchlings, and if so how those differences affected seafinding behavior under natural conditions. We found that leatherbacks were (i) about an order of magnitude less sensitive to the same light wavelengths used by the other species, and that (ii) those sensitivity differences were correlated with more circuitous orientation paths shown by leatherbacks during their seafinding crawl. Those contrasts were reduced under lunar illumination that heightened intensity contrasts between the landward and seaward view. We conclude that while the two groups of species are equally adept at locating the sea from the nest, and while they favor detection of the same light wavelengths, sensitivity differences may be responsible for contrasts in their orientation accuracy. Those contrasts may also make leatherbacks more susceptible to the disruptive effects of increasingly common artificial lighting on seafinding during this crucial early phase of migration.

BSP-6-6 Tran, LL*; Johansen, JL; University of Hawai'i at Manoa; *leontran@hawaii.edu*

Reproductive consequences of environmental stress in a Hawaiian coral reef fish

Rising temperatures, increased marine heatwave frequency and severity, and concomitant water deoxygenation resulting from anthropogenic climate change is increasingly affecting marine organisms worldwide. Tropical coral reef fish are particularly sensitive to these changes as the result of adaptation to the narrow temperature ranges and high oxygen saturation levels typical of coral reef ecosystems. Additionally, successful reproduction forms the basis for ecosystem productivity but is a highly sensitive life stage for reef fishes due to high metabolic demand. Both reproductive and metabolic processes are optimized under certain temperatures and high oxygen levels, thereby providing a

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mechanistic link between reproductive success and environmental stress. Focusing on a commercially important coral reef fish species, the convict tang (*Acanthurus triostegus sandvicensis*), this study compares the capacity of reproductive and non-reproductive adults to tolerate the combined effects of acute thermal stress and reduced oxygen availability that occur during marine heatwave events. We expected reproductively active fish to have lower aerobic metabolic scope and hypoxia tolerance than reproductively inactive fish following exposure to simulated marine heatwaves. Preliminary analysis indicated that metabolic rate increased with temperature while hypoxia tolerance decreased. Here we present our results and show how global climate change threatens to alter reproductive processes of reef fishes. As long-term population viability, ecosystem productivity, and the livelihoods of community subsistence fisheries all depend on the reproductive success of reef fishes, this work provides a critical step in clarifying the reproductive consequences of unabated climate change for coral reef fishes.

88-4 Treanore, ED*; Amsalem, E; Pennsylvania State University; *ezt5142@psu.edu*

Examining the combined effects of cold storage and CO2 narcosis on bumble bee queen reproduction

Diapause is a pre-programmed arrest of development allowing insects to survive in unfavorable environments. In adult insects, diapause termination is often followed by shifts in macronutrient allocation and a transition to reproduction. Interestingly, in some social insects, narcosis with CO_2 can be used to bypass diapause and induce reproduction, thus making it a useful tool for identifying conditions that trigger a shift to reproduction. Moreover, previous research suggests that CO_2 may improve queen productivity following diapause termination. However, how CO_2 narcosis and diapause act in concert to affect reproduction, and whether the mechanisms underlying the transition to reproduction are shared, remain unknown. Here, we investigated the effects of exposure to both diapause and CO_2 on queen reproduction in the common eastern bumble bee (*Bombus impatiens*). We narcotized queens with CO_2 following diapause-like conditions (cold storage) over a period of 2-weeks, 2-months, 4-months, or no cold storage, and compared their

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survival, egg-laying latency, and offspring production, with that of non-narcotized queens over the same length of cold storage. We found that CO_2 narcosis positively affected reproduction following no cold storage or a 2-week cold storage, but, did not have this effect following longer periods of cold storage. In line with previous research and regardless of CO_2 narcosis, survival decreased with cold storage length, with approximately 40% of queens surviving following 4-months compared with 80% after 2-months. Our data suggest that independently, CO_2 narcosis and cold storage of at least 2-months trigger the shift to reproduction, but this effect is not additive. Instead, CO_2 narcosis appears to have complex effects on queen survival and reproduction that vary with cold-storage length.

68-6 Treidel, LA*; Williams, CM; UC Berkeley; *lisa.treidel@berkeley.edu*

Resource acquisition, allocation, and energy production change in tandem through development to support flight or reproduction in wing-dimorphic crickets

Wing-dimorphism in crickets is maintained by a resource allocation-based trade-off between flight and oogenesis. Flightless short wing (SW) crickets preferentially divert nutrients to ovaries to support oogenesis, while flight capable long wing (LW) crickets divert nutrients to somatic maintenance to support metabolically active flight muscles and accumulate energy stores that fuel flight. Although the underlying metabolic basis of the flight-oogenesis trade-off is well characterized, we do not know whether the distinct physiological demands of flight and reproduction also drive shifts in resource acquisition and energy production capacity. We integrate data from two separate experiments, showing how resource acquisition (feeding behavior), allocation (tissue growth), and energy production capacity (mitochondrial function) change throughout the lifecycle. At the start of adulthood, SW crickets initiated rapid oogenesis and increased protein intake. However, when feeding on a protein-deficient diet ovarian synthesis by SWs was reduced, suggesting that without sufficient protein acquisition, biosynthetic demands of oogenesis could no longer be met. Additionally, a decline in mitochondrial energy production capacity accompanied the completion of ovarian synthesis by SWs on

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the seventh day of adulthood. LW crickets consumed carbohydrate-rich diets and mitochondrial function changed dynamically across adulthood. LW mitochondrial capacity for energy production peaked at the time of dispersal, but rapidly declined following loss of flight-capability. Together, this suggests that behavioral and physiological plasticity in resource acquisition and energy production have evolved along with life histories to enable shifts in resource allocations.

92-4 Trickey, AK*; Orbach, DN; Texas A&M University - Corpus Christi; *alyssa.trickey@gmail.com*

Effects of male dusky dolphin mating behaviors on durations and rates of copulation

The mating tactics and behaviors of cetacean (whale, dolphin, and porpoise) species are largely unknown. The use of drones provides a novel way to follow and video-record individual cetaceans during mating interactions and discern how specific behaviors exhibited by both sexes alter the number and duration of copulations. A drone was flown over mating groups of dusky dolphins (Lagenorhynchus obscurus) off Kaikoura, New Zealand. Forty-three videos were analyzed to determine if the behavioral sequences of particular males led to increased copulatory durations, higher rates of copulation, and reciprocated affiliative behaviors from females. The duration of specific male pre-copulatory behaviors impacted the durations of copulations. This pattern was most evident with prolonged inverted swims by males resulting in copulations with long durations. Specific male behavioral sequences that preceded copulatory positioning led to higher rates of copulation with females. Affiliative behaviors initiated by males and reciprocated by females, such as nuzzling and spiral swimming, tended to precede copulatory bouts. This study advances dolphin mating research by highlighting which behavioral sequences result in frequent and prolonged copulations. The aerial perspective provided by a drone enabled individual tracking of dolphins over time and a non-invasive approach that would not be possible by boat.

2-10 Trigg, SA*; Putnam, HM; Gurr, SJ; Mitchell, KR; Vadopalas, B; Roberts, SB; University of Washington, Seattle, WA, University of

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Exploring the tolerance of Pacific geoduck to low pH through comparative physiology, genomics, and DNA methylation

The Pacific geoduck clam is important in Native American culture, to ecosystems as biofilters and prey, and to the U.S. economy as a valuable fishery that provides revenue and jobs. To gain insight into how this species might fare with future ocean acidification, and if stress conditioning might be beneficial in aquaculture practices, we explored the effects of low static and variable pH exposure on juveniles and adults. We found that juveniles were able to overcome a developmental delay resulting from an initial low pH exposure, growing larger over time and when under a secondary low pH exposure. Genome characteristics and methylation variation supported these phenotypes, with altered DNA methylation occurring mainly within genes associated with specific biological processes. We found that adults experienced decreased survival and delayed reproductive development under static, but not variable low pH exposure. Offspring of adults exposed to variable low pH initially showed delayed larval development, but were able to compensate as juveniles and grew larger under variable low pH conditions while maintaining a lower, less variable metabolic rate. Taken together, stress exposure duration, intensity, and variation, and the developmental stage of the animal produce different phenotypes. These experiments show short-term rather than long-term and variable rather than static stress exposure give rise to beneficial phenotypes (e.g. less metabolic activity to achieve the same or greater size), and that DNA methylation is a mechanism by which these phenotypes can be expressed.

99-2 Tripp, JA*; Berrio, A; McGraw, LA; Matz, M; Davis, J; Thomas, J; Young, LJ; Phelps, SM; University of Texas-Austin, University of Texas-Austin and Duke University, Emory University, Emory University and CDC, Emory University and NIH, Emory University; *joel.tripp@utexas.edu*

Neurogenomics of the bonding brain

The formation of attachments between mated pairs is a defining feature of monogamous mating systems. Decades of research using microtine voles (genus *Microtus*) have uncovered many of the brain regions and pathways critical for the formation and maintenance of

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these bonds in monogamous mammals. Several studies have also explored the function of specific candidate genes in bonding, particularly the nonapeptides and their receptors, as well as dopamine and opioid receptors. However, so far, the greater gene expression changes that occur in response to and support of pair bond formation have not been more thoroughly explored. We used RNA-sequencing to observe changes in gene expression in response to mating in three brain regions critical for pair bond formation in two related species: the pairbonding prairie vole (M. ochrogaster), and the promiscuous meadow vole (M. pennsylvanicus). We sequenced transcripts from the amygdala, hypothalamus, and a region inclusive of the ventral pallidum and nucleus accumbens in virgins and at three time points after the onset of mating in both species. Differences in gene expression patterns were most strongly associated with species and brain region. We identified differential expression of gene categories across species and brain region and found specific genes that differ in expression in response to mating across species. In addition, we identified gene modules strongly associated with brain regions, as well as modules that correlated significantly with mating status in prairie voles, but not meadow voles. These results emphasize the importance of pre-mating differences in gene expression that confer the capacity to bond in prairie voles and identify new candidate genes which may play an important role in bond formation.

37-5 Truman, JW*; Konopova, B; Riddiford, LM; University of Washington, Biology Centre Czech Academy of Sciences; *lmr@uw.edu*

Effect of juvenile hormone on firebrat (Thermobia domestica) embryos

In insects, juvenile hormone (JH) facilitates postembryonic development but prevents metamorphosis. In the embryos of hemimetabolous insects, however, early JH exposure arrests embryonic growth and tissue patterning and elicits premature differentiation [Truman and Riddiford, *Phil. Trans. R. Soc. B* **374**: 20190070 (2019)]. We show here that in the basal, ametabolous firebrat, *Thermobia domestica*, application of JH III or the JH mimic (JHM) pyriproxyfen early in embryogenesis allows normal growth through the extended germband stage and secretion of the first embryonic cuticle; but then embryo differentiation stalls and

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limbs regress. Developmental anomalies are reduced as JHM treatment is delayed, and sensitivity to exogenous JHM is lost at dorsal closure as a second embryonic cuticle (cuticle of the first postembryonic instar) starts to be secreted and endogenous JH appears. Thus, as in embryos of basal hemimetabolous insects, JH can suppress early morphogenesis; but it has less effect on precocious differentiation as compared to locusts or crickets. JHM treatment beginning at hatching has no effect on the first two non-feeding instars, but the 3rd instar has an altered morphology, including reduced size, incomplete sclerotization of the mandibles and, often, reduced or no feeding. To elucidate the underlying molecular basis of the embryonic and postembryonic effects, we studied the mRNA profiles of the nymphal transcription factor (TF) Broad and the Krüppel homolog 1 (Kr-h1) TF induced by JH. Broad is maternally deposited in the egg, then declines during early development only to reappear as the germ band develops, then persist through most of nymphal development. It is also present during the nymphal intermolts. The regulation of these two TFs by the exogenous JH will be discussed.

S4-13 Tucker, KP*; Glaser, RL; Marx, M; Kniss, A; Moran, CE; Stevenson University; *kptucker@stevenson.edu*

Interdisciplinary collaboration in undergraduate service-learning

Service-learning is an experiential learning strategy where students learn course content and additional relevant skills through completing service with a community partner. Critical reflection is a key component of this pedagogy, requiring students to think about their experiences and how the course content paired with service connects to their lives and the world around them. When reflection is done well, it requires students to integrate expertise from their personal experiences, different disciplines, and the world at large. However, despite the increasing emphasis on interdisciplinarity in higher education, faculty teaching service-learning courses often remain in disciplinary silos. Classes are typically taught by one faculty member in one discipline regardless of the needs of the service-learning project. This is especially true in the sciences, even though the sciences are inherently interdisciplinary. Rarely, though, do science courses extend to relevant content and skills outside of the STEM disciplines. We

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propose that interdisciplinary collaborations between STEM and non-STEM courses enriches course content, provides a more comprehensive experience for students that highlights the application and interconnection of course content, and increases collaboration within our institutions. We will present a generalizable model for successful interdisciplinary projects and reflections using examples of collaborations between science/design and science/humanities. While the nature of course scheduling, academic department structure, and faculty workload can be barriers to collaboration between faculty, they are not insurmountable. The benefits to the students and the community far outweigh navigating these challenges.

73-11 Tucker, EL*; Mantilla, DC; Hsieh, ST; Temple University, Philadelphia, PA; *Liz.tucker@temple.edu*

Kinematics of running across hard and granular surfaces in specialist and generalist lizards

Terrestrial animals routinely encounter granular media, such as sand, dirt, or gravel. Granular media poses unique challenges to locomotion due to their changes between solid and fluid-like states as a response to differences in force application. Despite its ubiquity in the natural environment, it is still not well known how animals may be adapted morphologically or kinematically for running on hard versus granular surfaces. We ran three species of lizards representing a desert generalist (*Crotaphytus bicinctores*), a desert specialist (*Callisaurus draconoides*), and a fluid specialist (*Basiliscus vittatus*) along a 2 m long hard trackway and a fluidizable bed of poppy seeds ("sand"), while filming with a high-speed camera (Photron SA-3, 500 fps). We hypothesized that these lizards would run with similar velocity on the hard-flat trackway, however, desert and fluid specialists would outperform the desert generalists on sand. The sand proved to be a challenge for all three species of lizards. Desert specialists ran at similar speeds to fluid specialists but outperformed desert generalists. Both desert specialists and generalists ran slower on the sand than they did on the hard-flat surface. Failure to successfully compensate on sand resulted in higher duty factors for both species, with lower stride frequencies for the sand specialists and lower stride lengths for the desert generalists. The fluid

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specialists were able to maintain similar speeds between the two conditions, however, it displayed decreases in duty factor as well as stride length. While alteration of above ground kinematics explains some of the patterns that we are seeing in our results, it remains to be seen how adaptive foot use may be contributing to success across these two surfaces.

75-4 Tumminelli, AN*; Bartol, IK; Old Dominion University; *atumm002@odu.edu*

Fin motion patterns in swimming stingrays

Fin movement versatility in fishes is critical for avoiding predators, capturing prey, navigating complex environments, swimming efficiently at different speeds, and even properly positioning during mating. Many stingray species rely on both undulatory (wave-like) and oscillatory (flap-like) movements of their pectoral fins. The importance of these two fin motion patterns change in relation to multiple factors, such as lifestyle, environment, locomotory behavior, and swim speed. For this study, we focus on how wave and flap-like patterns change with swimming speed in Atlantic stingrays *Hypsanus sabinus*. Animals (20-30 cm disc width) were placed in a water tunnel and filmed swimming over a range of speeds (2 cm/s - 20 cm/s) using multiple high-speed cameras. The high-speed data were analyzed using proper orthogonal decomposition (POD) to decouple and identify dominant fin motions. The Atlantic stingrays exhibited multiple prominent POD fin modes, each with distinct frequencies and wavelengths. While stingrays relied heavily on undulatory fin motions throughout their speed range, the importance of oscillatory motions increased at higher swimming speeds, presumably to generate greater thrust via circulatory forces. Our data suggest that pectoral fin motions in Atlantic stingrays are multifaceted, with multiple POD modes comprising the total fin motion, and small changes in fin behavior can affect overall swimming performance.

71-3 Turner, ML*; Gatesy, SM; Brown University, Providence, RI, USA; *morgan_turner@brown.edu*

Intermetatarsal mobility in the American alligator

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Feet mediate animal-substrate interactions across an animal's entire range of limb poses used in life. Metatarsals, the 'bones of the sole,' are the dominant skeletal elements. In plantigrade animals, intermetatarsal mobility offers the potential for reconfiguration within the foot itself. Unlike most extant plantigrade animals, the proximal metatarsals in alligators are substantially dorsoventrally overlapped, or stacked. Alligators are capable of postural extremes—from a belly sprawl to a high walk to sharp turns—how does the unique foot morphology reconfigure to accommodate these diverse demands? Using marker-based XROMM, we measured metatarsal kinematics in three juvenile American alligators (*Alligator mississippiensis*) across their locomotor and maneuvering repertoire on flat surfaces. We found that regardless of limb placement, the metatarsals conform to the ground to maintain fully plantigrade contact throughout most of stance phase. In addition to intermetatarsal abduction (spreading), metatarsals dynamically reconfigure via differential pitching. As distal condyles maintain ground contact, the proximal elevation of either metatarsal I or IV causes the proximal transverse axis of the metatarsus to 'skew' relative to the distal transverse axis. As metatarsals pass through a skew range of 45 degrees, up to 65 degrees of individual metatarsal long axis rotation (LAR) reorients the direction of proximal stacking relative to the ground. Through a combination of skewing and LAR, metatarsals proximally reorient and are permitted to maintain plantigrade ground contact throughout a diversity of extreme limb poses. These data suggest that for the many extinct fossil archosaur relatives that share this morphology, intermetatarsal mobility likely plays a significant role in maintaining ground contact across greater postural extremes in these taxa.

92-6 Tweeten, KA*; Scollick, JA; St. Catherine University; *katweeten@stkate.edu*

Protein and DNA labeling techniques suggest that diploid populations of sexually reproducing Lumbriculus cross-fertilize

Diploid populations of *Lumbriculus* collected from lakes and sloughs in the Minnesota and Iowa sexually reproduce during the summer months. These worms have reproductive structures including atria, testes, ovaries, sperm sacs, male funnels, female funnels,

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spermathecae with ventrolateral pores, and protrusible penis sheaths. Histological analysis showed sperm in spermathecae suggesting that cross-fertilization was occurring. The objective of the project was to look for direct evidence of outcrossing. Worms labeled with the fluorescent dye, Hoechst 33342, appeared to transfer sperm to unlabeled worms. We consistently observed fluorescent sperm in homogenates made from reproductive segments of "recipient" worms incubated with labeled worms. However, we were able to detect labeled sperm in the spermathecae of only one of the recipients. We then explored other biological stains to monitor potential transfer of label from "donors" to the spermathecae of "recipient" worms. We utilized a fluorescent dye, rhodamine B, which binds to proteins including those in sperm and seminal fluid and neutral red, a stain taken up by living cells, labeling molecules associated with lysosomes. When worms labeled with either rhodamine B or neutral red were partnered with unlabeled worms, selective transfer of label to the spermathecae of unlabeled worms was observed. These results suggest that out-crossing is occurring in *Lumbriculus*. Experiments showing that cocoon production by *Lumbriculus* was dependent on worms being held together rather than individually further support cross fertilization in this freshwater annelid.

46-8 Tylan, C*; Langkilde, T; The Pennsylvania State University; *clh319@psu.edu*

Metabolic effects of consumption of and stings from fire ants, an invasive predator and prey of native lizards

The introduction of invasive species is a growing threat to ecosystems worldwide. Some invasive animals act as predators of native species that have not yet evolved defenses to them, while other invasive animals can be a novel food source for native species. In our system, the invasive species, the red imported fire ant (*Solenopsis invicta*), is both predator and novel prey of the native eastern fence lizard (*Sceloporus undulatus*). This allows us to explore the effects of both novel predator and prey on a native species. From previous research in this system, we know that fire ants have effects on the diet, immune function, behavior, and morphology of eastern fence lizards. Here we explored the possibility that consumption of and stings from fire ants might

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have metabolic effects. Consumption of fire ants in male, but not female, lizards was associated with a reduction in mass of crickets consumed. There was no significant different in weight gains between treatment groups for either sex, although this may be due to insufficient sample size. We are also exploring the potential for differences in respiration between experimental groups. This research suggests that invasive species may have different effects on the metabolism of native species depending on whether they are functioning as predator or prey.

S11-4 Udell, MAR*; Sipple, N; Smith, A; Vitale, KR; Thielke, LE; Oregon State University, Unity College; *monique.udell@oregonstate.edu*

Characterizing the dog-human bond: A comparative investigation of attachment relationships

Offspring-parent attachment bonds promote a proximity seeking - exploration balance in young, facilitating resilience when faced with novel experiences and environments. Research has suggested that, even in adulthood, pet domestic dogs (*Canis familiaris*) often form attachment bonds towards humans that resemble offspring-parent relationships. However it is unknown if dogs form the same kind of attachment bonds to other species in adulthood, including cohabitant dogs, or if the dog-human relationship is unique in this respect. In the current study we used the Secure Base Test to classify dog-human and dog-dog dyads into attachment style categories. We also evaluated behavioral indicators of stress reduction, proximity seeking and exploration. As in prior studies, we found that the majority of our dog-human dyads met the criteria for offspring-parent type attachment relationships; with individual differences in attachment style influencing the degree of stress reduction and exploration observed. Conversely, 41 out of the 43 dogs evaluated did not meet the traditional criterion for attachment towards their cohabitant dog. Instead behaviors observed in dog-dog relationships better matched those described in sibling attachment research. Overall, companion dogs were significantly less likely to elicit behaviors associated with attachment security in a focal dog when compared to owner presence. Dog-human attachment may play a distinct and important role in the success and resilience of adult dogs living in at least some anthropogenic

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environments. Bonds formed with other adult dogs may still be important, but likely serve a different function.

94-8 Uhrhan, MJ*; Fabian, JM; Siwanowicz, I; Lin, HT; Imperial College London, UK, Flinders University, Adelaide, AUS, HHMI Janelia Research Campus, Ashburn,
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The sensory apparatus of dragonfly wings: sensor distribution and morphologies

Animal locomotion involves complex interactions between body movements and a substrate. Movements are controlled by motor circuits and modulated by sensory feedback. Insect flight is especially challenging to control, because the wings deform passively in flight due to the interaction between aerodynamic, inertial, and elastic forces, a phenomenon known as aeroelasticity. Additionally, insect wing control and actuation is morphologically limited to the base of the wings. One animal that has evolved to not only cope but benefit from this phenomenon is the dragonfly, whose flight performance is outstanding in the insect world. Dragonflies can adjust the amplitude, frequency, and angle of attack of each of their four wings independently. Since flapping flight is inherently unstable, the control of flight kinematics requires rapid, accurate sensory feedback to ensure that precise aerodynamic forces are generated through coordinated movements of the wing. Here we present the first comprehensive map of the sensory apparatus expressed on the wings of dragonflies. We combined different imaging techniques to highlight the axonal routing, sensor diversity and distribution across a range of species. Based on the detailed sensory anatomy, we modelled the airflow around the sensors via computational fluid dynamic simulations to identify the perceptible stimuli. By linking the position of sensory structures on dragonfly wings with the appropriate surrounding airflow, our results give the first insight into the sensing aspect of fly-by-feel in the dragonfly.

1-11 Ujhegyi, N*; Bombay, B; Bókony, V; Plant Protection Institute, Centre for Agricultural Research, Pangea Cultural and Environmental Association; *ujhegyi.nikolett@gmail.com*

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Tolerant toadlets: anthropogenic noise and light pollution increases feeding efficiency in juvenile common toads (Bufo bufo)

Anthropogenic environmental change, such as noise and light pollution may have negative impacts on wild animals, yet several species maintain viable populations in urbanized areas. We investigated the effects of daytime noise and night at light on the foraging performance of juvenile common toads, an anuran amphibian that occurs throughout Europe in natural as well as anthropogenic habitats. We raised 26 common toads from eggs to 3 months of age in the lab, and tested their foraging success using house crickets (*Acheta domesticus*) as prey in two urban - like and two control situations. We put 20 small crickets into the toadlet's home box for 8 hours in each test, during which we exposed the animals to either a play-back of urban noise at day (45-98 dB) or light at night (39 lux) or no disturbance (a daytime and a nighttime control test). We found that the toadlets' feeding efficiency significantly increased during both anthropogenic treatments compared to the control situations. Toadlets that responded more strongly (in terms of change in foraging efficiency) to light at night had also stronger response to noise, suggesting consistent individual variation in tolerance to anthropogenic stress. Our results suggest that common toad is a species with good adaptability that may be able to exploit urban habitats due to its physiological or behavioral flexibility. This is in line with our earlier finding that urban toad tadpoles show more efficient regulation of the hormonal response to stress than tadpoles living in natural habitats.

60-2 Underhill, D*; Putnam, N; Valencia, V; Van Laar, TA; Telemeco, RS; California State University, Fresno & University of California Davis, California State University, Fresno; *dunderhill@ucdavis.edu*

Effects of early-life exposure to adult feces and natural substrate on the survival, phenotype, and gut microbiome of Western Fence Lizards

Sceloporus occidentalis can be difficult to rear in the laboratory despite maintaining robust populations in nature, with individuals frequently dying at 4-6 weeks post-hatching. We hypothesize that this high mortality results from captive-reared individuals failing to acquire important components of their gut microbiome that they

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typically acquire by consuming natural substrate or adult fecal material in the wild. To test this hypothesis, we reared S. occidentalis hatchlings in a two-by-two factorial design varying exposure to adult fecal material and natural substrate. We then measured survival and phenotype (SVL, Mass, TL) at four ages: 0 days, 7 days, 14 days, and 30 days post-hatching. Contrary to our predictions, treatment did not affect hatchling survival. Post-hatching survival was uniformly poor across all four treatments suggesting a lack of microbes or other vital factors in adult feces or natural substrate cannot explain high captive mortality. However, hatchling phenotype was affected by the treatments at 14 days post-hatching with animals exposed to feces or substrate generally being in better condition. This effect disappeared by 30 days post-hatching possibly due to diminishing sample sizes. To further explore this effect, we used 16S rRNA sequencing to characterize the microbial community within the guts of hatchlings from our experiment and wild-caught adults, as well as substrates and feeder insects. These data will allow us to elucidate the extent to which treatments affected the gut microbiome of hatchlings and what the primary sources of the gut microbiome are for this species.

108-7 Unfried, LN*; Teets, NM; University of Kentucky, Lexington, KY; *laura.unfried@uky.edu*

Ability of RCH to protect against physiological damage from sublethal chilling in Drosophila melanogaster

Rapid cold hardening (RCH) is a type of phenotypic plasticity in which a short chilling period increases tolerance to normally lethal temperatures. The role of RCH in protecting against lethal temperatures is well-established, but less is known about the effect of RCH in protecting ectotherms at the nonlethal temperatures experienced in the field. To better understand the role of RCH at temperatures commonly experienced in the field, we tested the hypothesis that RCH protects against sublethal cold injury in Drosophila melanogaster. In preliminary experiments we exposed flies to one of three treatments: control (25 for 2 h), direct chilling (-2 for 2 h), or RCH (4 for 1 h followed by -2 for 2 h); the results indicated that nearly 100% of flies survive at -2 degrees Celsius in both direct chilling and RCH treatments. In

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ongoing experiments, we are testing the ability of RCH to protect against suborganismal cold damage, preserve energy balance, and improve fecundity following cold stress. Together, these experiments will provide a thorough assessment of the ability of RCH to protect against sublethal cold injury.

BSP-7-9 Urban-Gedamke, E*; Conkling, M; McCarthy, PJ; Wills, PS; Pomponi, SA; Florida Atlantic University, Harbor Branch Oceanographic Institute, Fort Pierce, FL; *urbane@fau.edu*

3-D culture of marine sponge cells: comparison of methods

Sponges are ecologically and commercially important organisms whose simply organized cellular structure makes them especially amenable to cell culture. Cells cultured *in vitro* can increase our understanding of sponge cell growth and metabolism, and may reduce the need for wild sponge harvest for biomedical research, pharmaceuticals, and aquaculture. Recent studies have proven the ability to culture marine sponge cells in two-dimensions using an optimized nutrient medium. Here we demonstrate the successful implementation of multiple three-dimensional cell culture methods to culture cells from the marine sponge *Geodia neptuni* using the same optimized nutrient medium. The results of this research will advance current sponge cell culture methods, and further optimization of these techniques may lead to the *in vitro* production of marine natural products to meet biomedical demands and the culture of important marine sponge species for habitat restoration.

S11-6 Urfer, SR*; Promislow, DEL; Kaeberlein, M; Creevy, KE; Dog Aging Project, University of Washington, Seattle, WA, Dog Aging Project, Texas A&M Vetereinary Medicine & Biomedical Sciences, Seattle, WA; *urfers@uw.edu*

Heads or tails - random and not-so-random factors that influence dog lifespan

The privately owned companion dog is an emerging model in geroscience because it shares the human environment and its risk factors, is affected by many of the same age-related diseases, receives comparable medical care, and has excellent veterinary data available. In addition, the dog is the most phenotypically diverse

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animal species on the planet and includes breeds that represent hundreds of genetically distinct strains, which makes it an exciting model to research how these phenotypic and genetic differences affect clinical outcomes. A shared environment affecting health outcomes across species is referred to as One Health, and this has interesting implications for using dogs as models and sentinels for human epidemiology, including the study of aging, age-related disease and mortality. We analyzed patient records from three primary care US veterinary hospitals from a rural, suburban and urban environment to identify risk factors determining lifespan in n = 20,970 dogs using Kaplan-Meier and Cox Proportional Hazards models. This showed highly significant effects of weight and, after controlling for weight, spaying, environment, and anatomical features like brachycephaly, as well as a genotype-dependent effect of shortened tails. Our findings regarding body size, sex and spaying reflect previous data, indicating our sample was representative; however, living environments, as well as brachycephalic and tail length status have not previously been described as influencing life span in dogs. In addition to veterinary medicine, our results have interesting implications for human health in these environments under the One Health paradigm.

72-11 Usherwood, JR*; Granatosky, MC; McGowan, CP; The Royal Veterinary College, New York Institute of Technology, University of Idaho; *jusherwood@rvc.ac.uk*

Compromise between limb work and joint work minimization accounts for elbows-back, knees-forward arrangement in quadrupeds, and the 3-segment Z-leg configuration

Limb work, due to forces along and deflections of the entire limb from ground contact to centre of mass, is minimized with purely vertical forces. Joint work, the summed positive work performed at each of the joints, is minimized with force vectors oriented through the proximal (hip or shoulder) joint. Both parasagittal quadrupeds and bipeds use ground reaction forces generally oriented between the proximal joint and vertical. This suggests a compromise between limb work and joint work minimization due to some degree of between-joint power transfer facilitated by multi-joint linkages. Here, we describe how leg form and kinematics influence joint work demands. The elbows-back, knees-forward design reduces the joint

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work demand of a low limb-work, skewed, vertical force profile typical of walking quadrupeds. This geometry allows periods of high force (late stance in forelimb; early in hind) to be supported when the distal segment is near vertical, imposing low moments about the elbow or knee, while the shoulder or hip avoids high joint power despite high moments because the proximal segment barely rotates - translation over this period is due to rotation of the distal segment. To explore 3-element limbs, we apply empirical measurements of a hopping wallaby, using centre of mass motions and anatomical segment lengths to determine the manifold of potential configurations through stance; and search for the trajectory across this manifold that minimizes the joint work due to the measured forces and modeled moment arms and joint angular velocities. Joint work minimization predicts the knee forward, ankle backward Z-leg, and broadly agrees with empirical joint powers and kinematics. Further, the modeled Z-leg results in lower joint work than any feasible 2-link leg.

14-8 Usherwood, JR; The Royal Veterinary College; *jusherwood@rvc.ac.uk*

Why are the fastest runners of intermediate size? Contrasting scaling of mechanical demands and muscle supply of work and power

The fastest land animals are of intermediate size. Cheetah, antelope, greyhounds and racehorses have been measured running much faster than reported for elephants or elephant shrews. Can this be attributed to scaling of physical demands and explicit physiological constraints to supply? To approach this question, the scaling of mechanical work demand each stride and the mechanical power demand each stance are considered. Unlike muscle stress, strain and strain rate, mechanical work and power demands cannot be circumvented by changing the muscle gearing with minor adaptations in bone geometry or trivial adjustments to limb posture. Constraints to the capacity of muscle to supply work and power impose fundamental limitations to maximum speed. Given an upper limit to muscle work capacity each contraction, maximum speeds in big animals are constrained by the mechanical work demand each step. With an upper limit to instantaneous muscle power production, maximal speeds in small animals are limited by the high power demands during brief stance periods. The high maximum speed of the

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cheetah may therefore be attributed as much to its size as to its other anatomical and physiological adaptations.

1-8 Utt, DJ*; Foltz, SL; Radford University, Radford, VA; *dutt1@radford.edu*

The effects of artificial light on nesting and feeding behaviors in eastern bluebirds and tree swallows

Artificial light at night has been shown in numerous studies to impact the behavior of several species of wildlife across a wide variety of taxa. Research performed in the past has shown that animals living in environments where levels of artificial light are higher use that light to their advantage, hunting and foraging more often at night. Research has also shown that artificial light at night is harmful to many species as well, disrupting circadian rhythms and potentially increasing predation risk. In this project, we sought to understand the effects had by artificial light on nesting and foraging behaviors in the eastern bluebird (*Sialia sialis*) and the tree swallow (*Tachycineta bicolor*). We measured light levels at all boxes three times and monitored box occupancy and observed parental feeding visits to nestlings at sunset between June and August 2020. Statistical analyses are on-going, but we hypothesized that nestboxes with higher levels of artificial light around them were used less frequently than boxes that remained in the dark. We also predict that birds living in boxes exposed to higher levels of artificial light will feed more frequently and/or longer after sunset than those in darker boxes.

43-1 Üveges, B; Kalina, C; Szabó, K; Móricz, ÁM; Gabor, CR; Hettyey, A; Bókony, V*; Plant Protection Institute, Centre for Agricultural Research (PPI-CAR), Hungary, PPI-CAR, Hungary, Division of Clinical Immunology, University of Debrecen, Hungary, Department of Biology, Texas State University; *bokony.veronika@atk.hu*

Chronic stress influences defensive toxin production in toad tadpoles

Chemical defense is a crucial fitness trait in many organisms, yet its physiological regulation in vertebrate animals is poorly understood. Bufadienolides, the main defensive chemicals of common

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toads (*Bufo bufo*), are toxic to predators and other natural enemies, and their synthesis is upregulated by several stressors including predation risk, high competitor density, and pollutants. We hypothesized that bufadienolide production may be stimulated either by corticosterone (CORT), the main glucocorticoid hormone of amphibians, or by the same upstream regulators that stimulate CORT. To test these alternatives, we treated toad tadpoles with 125 nM CORT or 110 μM metyrapone (a CORT synthesis inhibitor that stimulates the upstream regulators by negative feedback) for 2 or 6 days, and then measured their total bufadienolide content. We found that CORT release rates were increased strongly by CORT treatment and less strongly by metyrapone treatment regardless of treatment duration, but only the 6-days treatments affected toxin production. CORT treatment significantly decreased bufadienolide content, and metyrapone treatment showed a similar but weaker effect. These findings suggest that bufadienolide synthesis is not stimulated by CORT; rather, it may respond to stressors via some other regulatory compound that is involved in the stress response. Thus, environmental stress in general, and endocrine disrupting chemicals in specific, may interfere with toxin production, which may affect the fitness of toads and their predators and competitors.

84-3 Valdecantos, S; Wenner, SM; Robertson, JM; Espinoza, MH; Lobo Terán, C; Espinoza, RE*; Universidad Nacional de Salta and Consejo Nacional de Investigaciones Científicas y Técnicas, California State University, Northridge, Valley International Preparatory High School, Universidad Nacional de Salta; *robert.e.espinoza@csun.edu*

Why do mothers care? Assessing the benefits of female-neonate associations in a viviparous lizard from the Argentine Puna

Parental care (PC) is rare in squamate reptiles and few studies have identified the benefits selecting for this form of grouping behavior in nature. We conducted a multiyear investigation of *Liolaemus multicolor*, a high Andean viviparous lizard that exhibits putative PC in the form of long-term associations between adult females and neonates. We studied these lizards at Nevado de Acay, Salta, Argentina (~4300 m) by (1) employing mark-recapture and focal animal observations to quantify the rate and duration of female-neonate associations in nature; (2) conducting a kinship analysis of ~500 SNPs to determine whether females grouping with

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neonates were their mothers; and (3) introducing conspecifics to focal females with and without neonates to assess differences in aggression and whether females defended associated neonates in nature. Our investigation revealed (1) females formed stable associations with 1-4 neonates for up to 4 mo; (2) most (84%) of our female-neonate focal groups (n = 13) represented mother-offspring associations; and (3) females with neonates were more aggressive towards conspecifics, particularly adult males, than unassociated females. These results support our hypothesis that long-term mother-offspring associations in *L. multicolor* likely confer fitness advantages by improving neonate survival in the harsh environment of the Argentine Puna. Future studies will compare the long-term survival of orphaned and mother-associated neonates.

63-1 Valentini, AL*; Garcia, M; Vargas, R; Steffenson, M; St. Edward's University; *avalenti@stedwards.edu*

Immunological response to leg autotomy in the wolf spider Tigrosa helluo

Autotomy is a widespread phenomenon in which an organism will voluntarily lose a body part. In spiders, this behavior is typically used as a defensive strategy in which the spider will sacrifice a leg to escape a predator. However, losing a leg may expose the spider's hemolymph to the environment, potentially providing an avenue for pathogens to infect the spider. The goal of this study was to determine if the loss of a leg has an immunological cost in the wolf spider, *Tigrosa helluo*. Spiders were collected on the St. Edward's University campus at night. Each spider had their physical fitness determined by racing them down a plastic tube and recording their running speed. Spiders were assigned to either a control group that kept all of their legs, or a treatment group that had one randomly chosen back leg removed. Spiders in treatment groups were then further assigned to time intervals of ten minutes progressing up to a maximum of 60 minutes (ex. 10, 20,...60). Spiders designated in a treatment group with a leg removed had their wound packed with soil to introduce environmental pathogens, and were then acclimated for the appropriate time interval before hemolymph extraction; hemolymph was then extracted from all spiders. Protein assays indicated a

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significant difference among the time intervals with a spike in protein levels at 60 minutes post-autotomy. However, prophenoloxidase (PPO) showed no significant difference among time intervals, though PPO activity showed a trend of increasing at the 60-minute time point that requires further examination.

7-9 van Bijlert, PA*; van Soest, AJK; Schulp, AS; Vrije Universiteit Amsterdam and Naturalis Biodiversity Center, Netherlands, Vrije Universiteit Amsterdam, Netherlands, Naturalis Biodiversity Center and Utrecht University, Netherlands; *pasha.vanbijlert@naturalis.nl*

Biomechanics of tail heaving predict preferred walking speed of Tyrannosaurus rex

Animals minimize cost of transport by selecting gaits tuned to the natural frequencies of their body parts. This allows estimation of tail natural frequency and preferred walking speed (PWS) of *T. rex*, using an approach we introduce as the Natural Frequency Method. During walking, the tail was subject to flexion torque due to gravity and contractions of the tail musculature, which was counteracted by the caudal interspinous ligaments. Tail heaving with each step caused peaks in ligament strain, making them an important site for elastic energy storage. This is comparable to the nuchal ligament's role in ungulate neck movement during walking. Based on high-fidelity 3D scans of the caudal vertebrae of adult *T. rex* specimen RGM.792000, we constructed a biomechanical model of the ligament-suspended tail and determined its natural frequency (0.66 s^{-1}, 0.56-0.79), which we combined with step lengths from trackway data to find PWS (1.28 m s^{-1}, 1.09-1.54) for *T. rex*. Various methods to reconstruct locomotor abilities of extinct dinosaurs have led to conflicting results. Due to the uncertainties involved, it is important to explore independent lines of evidence. Our method explores dinosaur PWS without being affected by estimated muscle mass or hip-height, and therefore opens up a new research avenue within paleo-biomechanics. Our results are closely in line with extant taxa, regardless of size and locomotor mode, which may suggest that previous methods that neglect tail dynamics are overestimates. Steady-state locomotion has a large effect on an animal's ecological niche, and our method can therefore provide us

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with new insights into possible gait patterns, habits and locomotor ability of dinosaurs.

106-1 Van Buren, EW*; Ponce, IE; Mydlarz, LD; University of Texas at Arlington; *emily.buckley@uta.edu*

Identifying Candidate PPOs in Corals: Is the melanin synthesis cascade more similar to humans or insects?

Identifying Candidate PPOs in Corals: Is the melanin synthesis cascade more similar to humans or insects? Authors: Emily Van Buren, Ivan Erasmo Ponce, Laura D Mydlarz General abstract: Melanin deposition that creates tissue discoloration is a phenotypic trait of coral immunity that has studied during disease outbreaks on coral reefs. Regardless of its presence in various diseases, the melanin synthesis cascade in coral species has remained elusive. To further identify the melanin pathway in several coral species and the genes involved in melanin synthesis, we performed BLAST searches with available mammalian, Insecta, and other cnidarian species' melanin synthesis KEGG pathways. We also compare the main prophenoloxidase (PPO) candidate enzymes involved in melanin synthesis; tyrosinase, catechol oxidase, and laccases on available genomes using STRING. Composition Profiler was utilized to identify the enrichment of specific amino acids in cnidarian PPO candidate enzymes. We also use transcriptomic and proteomic data sets from Eunicea Black Band (EBB) disease to investigate melanin cascade enzymes in a disease model. EBB is unique due to its highly melanized immune response and serves as a model coral for this pathway. Preliminary data suggests the melanin cascade is more similar to Hydra vulgaris (55%) and Homo sapiens (40%) than insect species such as Aedes aegypti (23%) and Drosophila melanogaster (18%). By elucidating the melanin cascade in corals, we can understand its function and role of the relevant PPO candidate enzymes during specific disease events.

65-3 van Hall, ES*; Korsmeyer, KE; Hawaii Pacific University; *evanhall1@my.hpu.edu*

Temperature preference and aerobic scope in Zebrasoma flavescens and the response to rising sea temperatures

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Climate change is predicted to increase both sea surface temperatures, as well as the frequency and severity of localized heating events, a phenomenon which may threaten the biodiversity, integrity and function of tropical coral reef ecosystems. This study determined the temperature preference and aerobic scope for a Hawaiian surgeonfish, the yellow tang (*Zebrasoma flavescens*), acclimated to two temperatures: 27° C, an average summer sea surface temperature (SST) in Hawaii, and 31° C, an elevated SST. Thermal preference of individuals from both groups were tested over a 24-hour period in an annular preference chamber with a gradient from 24 to 34° C. Additionally, oxygen consumption rates were measured in a swimming respirometer to determine their standard and maximum metabolic rates, aerobic scope and swimming performance. Preliminary results for temperature preference suggest that fish from both treatments prefer temperatures below the current summer SSTs in Hawaii and may predict a population shift to cooler waters, either higher latitudes or greater depths, as the ocean warms in the next century. Additionally, the measures of aerobic scope following acclimation to warmer water will help understand how temperature change may affect fitness. A reduced aerobic scope would indicate that less energy could be allocated for essential activities such as reproduction, foraging and swimming.

72-9 Van Stratum, B*; Clark, J; Shoele, K; Florida State University; *bjv02@my.fsu.edu*

Modeling internal forces in limbless organisms during locomotion

The motion of limbless animals arises as the result of the interaction of their central nervous system, muscle and connective tissue, bone, and their environment. Two such important interactions are the highly elastic titin inside of muscle fiber and the damping that results from the interaction of muscle fibers during expansion and contraction. Prior work in the area of snake locomotion has imposed the kinematics of slithering and analyzed resulting motion. To gain an understanding of internal forces and stresses, we apply traveling waves of the moment to a non-linear visco-elastic beam model. Consistent with the friction properties of the scales of snakes and limbless lizards, environmental forces are modeled using anisotropic Coulomb friction. We find that by varying the crawler body's internal stiffness, the crawler's

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performance and direction can be altered. Further, we identify the parameters that produce optimally efficient gaits. We find that these parameters that produce optimal speed and efficiency are functions of the environmental friction. A better understanding of how these internal parameters affect locomotion can be employed in designing soft robotic platforms for surgery, search and rescue, and exploration.

66-11 van Veen, WG; van Leeuwen, JL; Muijres, FT*; Experimental Zoology Group, Wageningen University & Research, The Netherlands; *florian.muijres@wur.nl*

Acceleration-reaction forces in high-frequency flapping insect wings, a systematic numerical study

To produce the aerodynamic forces required for flight, two-winged insects (*Diptera*) beat their wings back and forth at high wing-beat frequencies. Because the angular accelerations of this oscillating wing system scales quadratic with the wing-beat frequency, acceleration-reaction forces as a result of wing stroke-accelerations are expected to be particularly high for these flying insects. Here, we used computational fluid dynamics (CFD) simulations to systematically study how acceleration-reaction forces and airflow dynamics depend on wing morphology, wing-stroke rate and wing-stroke acceleration. Based on these simulations, we developed an aerodynamic model that captures the stroke-acceleration forces based on the wing-beat kinematics and wing morphology. Furthermore, we explicitly modeled the interaction of the stroke-acceleration with a selection of other known aerodynamic mechanisms. Our analysis shows that particularly for high-frequency flapping flyers such as mosquitoes, the acceleration-reaction forces contribute substantially to aerodynamic lift and drag production.

98-2 Van Wassenbergh, S*; Pauly, E; Abourachid, A; University of Antwerp, Belgium, Muséum National D'Histoire Naturelle, Paris, France; *sam.vanwassenbergh@uantwerpen.be*

How woodpeckers manage to retract their beak quickly after it got stuck in wood

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Woodpeckers powerfully peck at trees to remove the bark while searching for food, or to create nest holes. Similar to what happens when we hammer a nail into wood, their beak regularly gets stuck. Our high-speed videos of pecking by black woodpeckers (*Dryocopus martius*) showed that these birds are able to free their beak quickly and seemingly effortlessly. A kinematic analysis revealed what happens shortly after the beak is fully immobilised after impact into the wood. With a view on the woodpecker facing the left, the head rotates clockwise by a few degrees about the quadrate. This head rotation is inevitably linked to a counter-clockwise rotation of the upper beak: while the proximal end is lifted, the tip of the upper beak is retracted. This implies a few degrees of flexion about the nasofrontal hinge. This backward pull of only the tip of the upper beak creates free space between the beak and the punctured hole, and therefore subsequently enables the retraction of the entire beak without substantial shear. The entire process of beak liberation generally takes less than 20 ms. It demonstrates the counter-intuitive value of maintaining cranial kinesis between the upper beak and the braincase in a species adapted to deliver forceful impacts with its beak.

65-5 Van Wert, JC*; Hendriks, BJ; Ekström, A; Patterson, DA; Cooke, SJ; Hinch, SG; Eliason, EJ; University of California, Santa Barbara, University of British Columbia, University of Gothenburg, Simon Fraser University, Carleton University; *jcvanwert@ucsb.edu*
Population-specific variability in the thermal performance of Fraser River Chinook salmon
Climate change is causing large scale declines in Pacific salmon, and warming rivers are causing high levels of *en route* mortality in spawning adults. In the Fraser River in British Columbia, Canada, only two of the thirteen Chinook salmon (*Oncorhynchus tshawytscha*) populations evaluated by COSEWIC were not assessed as threatened or endangered. However, little is known about the thermal tolerance of adult migrating and spawning Chinook salmon, and if differences exist among populations in physiological performance. We compared thermal performance of maturing Chinook captured from their spawning migrations from two populations: coastal fall-run Chinook (~100 km cooler migration) and interior summer-run Chinook (~500 km warmer migration), by measuring resting and maximum metabolic

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rates, aerobic scope (AS), and post-exercise recovery during acute exposure to current and future projected Fraser River temperatures (12, 18, 21, 24° C) encountered during their spawning migration. The temperature threshold for 50% mortality was 21° C for the coastal Chinook and 23.5° C for the interior Chinook, indicative of a lower thermal tolerance in the coastal population. Although both populations shared an optimal AS at 14.5° C, AS declined more rapidly with increasing temperature in the coastal population. Finally, while post-exercise recovery was impaired in both populations at high temperatures, the coastal population had a slower recovery compared to the interior population. Our findings suggest that migrating and spawning adult Chinook are vulnerable to environmental warming and display among-population variability in thermal performance.

52-7 Vanhaesebroucke, O*; Larouche, O; Cloutier, R; Université du Québec à Rimouski, Canada, Rice University, Houston, TX; *olivia.vanhaesebroucke@uqar.ca*

Inside-out view in variational modularity of an actinopterygian using 3D geometric morphometrics

Actinopterygians are the most diversified clade of extant vertebrates. They have successfully colonized most aquatic environments, and their impressive morphological disparity bears witness to this ecological diversity. An intrinsic property of biological organization thought to facilitate morphological diversification is modularity. Indeed, the quasi-independence of some anatomical/morphological units has been suggested to increase the evolvability of organisms and the morphological disparity. The main goal of the present study is to quantify patterns of variational modularity in a model actinopterygian, the zebrafish (*Danio rerio*), using 3D geometric morphometrics on osteological structures isolated from micro-CT-scan data. 72 landmarks were digitalized along the cranial and postcranial ossified regions of 30 specimens of adult zebrafish. Modularity hypotheses were tested using two methods, the covariance ratio and graphical modelling. The hypothesis of the paired fins constituting a variational module is strongly supported, as well as the hypothesis of median and caudal fins forming another module, which may be associated to the subcarangiform locomotion of zebrafishes. The skull showed

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relatively weak overall integration, but it was tightly integrated with the rest of the body. This may suggest that the cranium is a modular structure, yet that some elements remain functionally integrated with postcranial regions. Our results provide additional support for the recognition of similar modular hypotheses that had already been identified based on the external morphology of various teleosts. Thus, the internal and external modularity patterns are congruent and at least two variational modules have been identified.

2-6 Varney, RM*; Speiser, DI; Kingston, ACN; Kocot, KM; Univeristy of Alabama, Univeristy of South Carolina, University of Tulsa, University of Alabama; *rvarney@crimson.ua.edu*

Chitons on the cutting edge: the biomineralization of iron-clad teeth in Acanthopleura granulata

Chitons (Polyplacophora) are intertidal molluscs that rasp algae from rocks using teeth coated with iron. Chitons produce these iron-clad teeth throughout their lifespans on a conveyor-belt like feeding organ called a radula. To better understand the molecular mechanisms chitons use to biomineralize iron, we sequenced the genome of the West Indian Fuzzy Chiton, *Acanthopleura granulata*. We found *A. granulata* has a greater number of genes potentially regulated by iron than other molluscs. We also investigated the physiological environment within the radula. We discovered an iron mineralization zone of 6-8 tooth rows in which *A. granulata* facilitates magnetite crystallization by lowering the pH of radula tissues to ~4. We expected chitons to use free iron (iron not bound to proteins) in radula biomineralization, but free iron causes oxidative stress. Consequently, we analyzed relative amounts of reactive oxygen species (ROS) across the radula of *A. granulata* and found more ROS in the iron-rich regions of the radula compared to regions without iron, indicating higher oxidative stress where iron biomineralization is taking place. Informed by physiology, we sequenced transcriptomes from developmentally distinct regions of the radula and characterized gene expression patterns associated with iron biomineralization. This is the first study of a chiton radula to use physiological information to guide analyses. Studies of chitons like *A. granulata* facilitate future

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investigations of the mechanisms and evolution of metal biomineralization in animals.

BSP-5-3 Vasquez, D*; Park, AW; University of Georgia; *dvasquez@uga.edu*

Drivers of parasite abundance: Environmental vs host effects

In contrast to free-living species, theory governing parasite abundance is lacking, partly due to a lack of quantitative parasite population data. Parasite abundance is controlled by its niche, which is partly environmental and partly host habitat. For macroparasites, abundance is dictated by host abundance, parasite intensity, parasite prevalence, and an ability to survive and develop outside of the host. The natural variation in parasite abundance has implications for infection pressure in host species and understanding what drives this variation is an important knowledge gap. In this study we used a 30-year longitudinal study of white-tailed deer with intensity data scored for 16 macroparasites in 2364 deer sampled in 180 US counties to ask (i) which component of parasite abundance most strongly correlates with abundance itself? (ii) How consistent are patterns across different parasite species? (iii) And what environmental factors explain geographical variation in parasite abundance? To answer these questions, we estimated parasite abundance for each county as the product of parasite prevalence, parasite intensity, and deer abundance. We calculated rank correlation coefficients for each component of parasite abundance with abundance itself. Lastly, we performed statistical modeling to relate county-level abundance to underlying environmental data obtained from WorldClim. We found parasite intensity to be most positively and significantly correlated with parasite abundance, which suggests that attaining high intensity infections in hosts is most important for achieving high parasite abundance. Furthermore, temperature seasonality constrains the abundance of several parasite species; however, this pattern is parasite specific. Collectively, this illustrates that parasite abundance is governed by both host and non-host components of its niche.

57-7 Vasquez, A A*; Walker, X N; Ram, J L; Miller, C J; Wayne State

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University, Detroit, Michigan; *avasquez@wayne.edu*

Prey choices and behavior of water mite predators of mosquito larvae from nearshore habitats of the Laurentian Great Lakes

Water mites are aquatic arachnids and ubiquitous inhabitants of freshwater habitats. Water mites are the most biodiverse arachnids and play a prominent role as predators, parasites and prey. They have also been reported to be useful as bioindicators of water quality and as a potential biocontrol for mosquitoes. At the Healthy Urban Waters field station, we have collected many water mite specimens and conducted feeding experiments to ascertain if they prey on mosquito larvae. Our preliminary observations on 7 genera identified 2 potential water mite predators of mosquito larvae. Predation was documented identifying water mite-mosquito feeding phenomena. Here we report on predatory behavior and prey choices of water mites from Point Rosa Marsh and Lake St. Clair.

50-5 Vasquez-Kuntz, K; Kitchen, S; Conn, T; Vohsen, S; Chan, A; Vermeij, MJA; Page, C; Marhaver, K; Baums, IB*; Pennsylvania State University, CARMABI Foundation, Mote Marine Laboratory; *baums@psu.edu*

Juvenile corals inherit mutations acquired during their parent's lifespan

Repeated coral bleaching events represent a strong selective force that is changing the genetic composition of surviving coral populations. Successful sexual reproduction of these survivors is the most likely means of adaptation. However, the dominant mode of reproduction in corals is often asexual, e.g., via breakage of pieces of the colony. In this way, coral genets can persist for thousands of years while accumulating post-embryonic mutations. We posit that this pool of mutations may be an alternate mechanism of adaptation, that is, if they are heritable. Analysis of genetic marker inheritance (Microsatellites and SNPs, validated via RFLPs) demonstrate that Elkhorn coral (Acropora palmata) colonies transfer post-embryonic mutations to the next generation. Larvae that shared a post-embryonic mutation with their parent were almost always produced via parthenogenesis or selfing and thus uniparental in origin. Hundreds of these larvae developed and grew normally. The discovery of uniparental larvae harboring post-embryonic mutations means that these mutations have the potential for much broader

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dispersal compared to mutations that are spread via fragmentation. As sexual reproduction continues to decline in the Caribbean, production of larvae carrying post-embryonic mutations may provide an alternative route for adaptation. The discovery of inheritance of post-embryonic mutations in an animal challenges our general understanding of animal adaptation and prompts a deeper examination the role of post-embryonic mutations in modular animals.

38-3 Vaughn, PL*; McQueen, W; Gangloff, EJ; Ohio Wesleyan University; *plvaughn@owu.edu*

Location, location, location: Lizard sprint speed in various environments demonstrates morphology-performance trade-offs

An organism's morphology (how its body is shaped) affects its performance (how effectively it carries out tasks like sprinting and climbing). This relationship can change in different contexts. For example, we might expect to find trade-offs whereby beneficial morphology in one environment can be detrimental in another environment. Furthermore, understanding how morphology affects performance in novel environments is necessary to understand how invaders can be successful. We tested this morphology-performance relationship in a successful global colonizer, the common wall lizard (*Podarcis muralis*), to address three primary questions: (1) Under what substrate conditions do these invasive lizards best perform? (2) Are there any within individual performance trade-offs (do lizards who run faster on one substrate run slower on another)? (3) What aspects of morphology most directly affect sprint performance under different conditions? We measured sprint speed with a full-factorial design of substrate type (cork bark, artificial grass, and sandpaper), sprinting elevation (level, incline), and obstacles (presence, absence). We also measured a suite of body dimensions important for locomotion, including tail length and limb dimensions. Lizards performed best on artificial grass without obstacles, but on cork with obstacles. Surprisingly, lizards consistently performed better running uphill compared to a flat track on all substrates. We also found significant negative correlations among all substrates, though strongest between sandpaper and the other two substrates. Finally, the advantage of larger body size in lizards disappeared when obstacles were present. These results demonstrate the complex limitations and

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trade-offs shaping organismal performance and provide insight into the mechanisms allowing colonization of novel environments.

36-9 Vaz, DB*; Hilton, EJ; Museum of Comparative Zoology, Harvard University, Virginia Institute of Marine Science, William and Mary; *dbistonvaz@fas.harvard.edu*

Stick together and act as if you belong: ontogeny and evolution of gill arches of Batrachoidiformes

Batrachoidiformes are benthic fishes that build spawning nests in intertidal rocky habitats. These species, which produce large eggs that are protected by the parents, lack larval dispersal. Rather, their larvae are attached to the nest and are nourished by their large yolk sac. The shift from a feeding, free-swimming to sedentary larva can lead to changes in skeletal development, especially in those structures associated to feeding and locomotion, which are typically among the earliest elements to form in teleostean larvae. To assess such changes, an ontogenetic series of Plainfin Midshipmen, Porichthys notatus (5 to 28 mm TL), was collected and cleared-and-stained to observe ontogenetic changes in the skeleton. In P. notatus the ossification of feeding-related bones, such as pharyngeal tooth plates, occur relatively later than in other percomorphs with free-swimming larvae. We observed that the single cartilaginous element positioned posterior to basibranchial three does not belong to the basibranchial series. In early stages (6.8-7 mm NL), hypobranchial four (HB4) is present and distinct as a pair of elements. Around 7.5 mm NL, the paired HB4 fuses into a single median element positioned posterior to basibrachial three; it remains cartilaginous and distinct in adult stages. The morphological similarity of this median element across the diversity of Batrachoidiformes suggests that having the left and right HB4s fused into a single cartilage has occurred in the entire order. Implications of this and other characters of the ventral gill arches of Batrachoidiformes will be discussed.

74-9 Vega, CM*; Ashley-Ross, MA; Wake Forest University; *vegacm11@wfu.edu*

Tiger salamanders (Ambystoma tigrinum) increase foot contact

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surface area on challenging substrates during terrestrial locomotion

Animals live in heterogenous environments which have a variety of substrates that differ in their roughness, texture, and other properties, all of which may alter locomotor performance. Despite such natural variation in substrate, many studies on locomotion use noncompliant surfaces that either are unrepresentative of the range of substrates experienced by species or underestimate maximal locomotor capabilities. The goal of this study was to determine the role of forefeet and hindfeet on substrates with different properties during walking in a generalized sprawling tetrapod, the tiger salamander (*Ambystoma tigrinum*). Adult salamanders (n=4, SVL =11.2-14.6 cm) walked across level dry sand, semi-soft plaster of Paris, wet sand, and a hard, noncompliant surface (table) - substrates that vary in compliance. Trials were filmed in dorsal and anterior views. Videos were analyzed to determine the number of digits and surface area (SA) of each foot in contact with the substrate. The SA of the forelimbs contacting the substrate was significantly greater on dry sand and plaster of Paris than on wet sand and the table. The SA of the hindlimbs contacting the substrate was significantly greater on dry sand than on all other substrates. There were no significant differences in the time that the fore- or hindfeet were in contact with the substrate as determined by the number of digits. We conclude that salamanders modulate the use of their feet depending on the substrate, particularly on dry sand which is known to increase the mechanical work and energy expended during locomotion owing to the fluid nature of its loose particles. More studies are needed to test a wider range of substrates and to incorporate behavioral data from field studies to get a better understanding of how salamanders are affected by different substrates in their natural environment.

2-11 Venkataraman, YR*; Roberts, SB; University of Washington; *yaaminiv@uw.edu*

Influence of ocean acidification on Pacific oyster (Crassostrea gigas) DNA methylation

As negative effects of ocean acidification are experienced by coastal ecosystems, there is a growing trend to investigate the effect ocean acidification has on multiple generations. For

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example, temporarily exposing adult Pacific oysters (*Crassostrea gigas*) to low pH prior to gametogenesis yielded a maternal effect – larval abundance was lower when females were exposed to low pH four months prior to spawning. The documented effect on Pacific oyster larval abundance indicates a potential role for epigenetic modifications, specifically DNA methylation, in response to ocean acidification. To assess how ocean acidification affects the Pacific oyster epigenome and uncover mechanisms behind the observed maternal effect, DNA was extracted from female oysters exposed to either low pH (7.31 ± 0.02) or ambient pH (7.82 ± 0.02) conditions for seven weeks. Whole genome bisulfite sequencing was used to identify methylated regions. The predicted function of genes containing differentially methylated loci location suggests a role for DNA methylation in acclimating to adverse conditions. Understanding a possible mechanism for phenotypic plasticity and acclimation across generations is valuable when considering organismal ability to persist in the face of environmental change.

29-1 Verdes, A*; Saarenpää, S; Junoy, J; Riesgo, A; Giacomello, S; Natural History Museum, UK and Museo Nacional de Ciencias Naturales, Spain, Science for Life Laboratory, Sweden, Universidad de Alcalá, Spain; *aida.verdes@gmail.com*

Visualization of toxin gene expression patterns in ribbon worm tissue sections by spatial transcriptomics

Ribbon worms (Nemertea) are active predators that use a proboscis to inject toxins into prey and defend themselves with toxic epidermal mucus. Nemerteans do not have distinct multi-cellular venom glands, instead toxins are secreted by cells lining the body wall and proboscis epithelia. The lack of a distinct gland has prevented the use of traditional venomics approaches to investigate their venom. Spatial Transcriptomics (ST) is a novel technology that allows to visualize and quantify transcriptomes within histological sections at 100 μm resolution. It facilitates the identification of toxins and their distribution within the tissue, revealing venom composition and producing tissue simultaneously. We adapted the method to analyze cryosections of 3 biological replicates from the species *Cerebratulus marginatus*, obtaining 3.5 million UMIs per replicate. After dimensionality reduction and clustering of RNA expression data, we identified 9 clusters linked

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to specific histological features. Proboscis and epidermis were the most distinct clusters, suggesting their profiles might be driven by toxin genes not expressed elsewhere. We mapped the expression data of mucus toxins such as nemertide alpha-1 and cytotoxin A-III on the tissue, revealing their distribution is not restricted to the epidermis. We also identified genes differentially expressed in the glandular epithelium of the proboscis, which may represent novel predatory toxins. Our findings suggest there is a hidden diversity of nemertean toxins and illustrate the capability of ST to investigate challenging venomous organisms, such as those without distinct venom glands or where venom cannot be milked.

62-3 Verdi, R*; Tredo, S; Hua, J; Binghamton University; *rverdi1@binghamton.edu*
When you eat matters: The effects of feeding frequency on tadpole growth and susceptibility to enemies
As human activities continue to alter natural ecosystems, understanding how we modify resource availability has important implications for an organism's fitness. While much of our understanding focuses on the consequences of resource limitation or supplementation on fitness, increasing evidence suggests that shifts in an organism's feeding frequency also contributes to fitness. In this study, we evaluate how variation in feeding frequency ("consistent" diet- 3x/week, "fluctuating" diet- 2x/week, "gorge" diet- 1x/week) influences four metrics of amphibian fitness: (1) ability to avoid predators, (2) ability to defend against a common trematode parasite, (3) mass at metamorphosis, and (4) time to metamorphosis. We found that feeding frequency did not alter tadpole susceptibility to predation. In contrast, feeding frequency modified tadpole susceptibility to trematodes, mass, and time to metamorphosis. Despite holding food availability constant, tadpoles in the gorge and fluctuating diet were 32% and 18% more susceptible, respectively, to parasites compared to tadpoles in the consistent diet treatment. Similarly, tadpoles in the gorge and fluctuating diet were 11% and 8% smaller, respectively, compared to tadpoles in the consistent diet treatment. Finally, tadpoles in the gorge and fluctuating diet reached metamorphosis 42% and 28% slower, respectively, compared to tadpoles in the consistent diet treatment. Collectively, this study

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suggests that shifts in feeding frequency has the potential to influence multiple metrics of amphibian fitness. As variation in resource availability is expected to increase over time due to human activities, understanding the relative contribution of resource limitation/ supplementation vs. shifts in feeding frequency on fitness may have important conservation implications.

78-4 Vernasco, BJ*; Cornelius, JM; Watts, HE; Washington State University, Oregon State University; *ben.vernasco@wsu.edu*

Assessing the impact of social cues on the termination of migration in a nomadic migrant, the pine siskin (Spinus pinus)

Many animals make seasonal movements between spatially-distinct habitats to capitalize on pulses of resources. The decisions of when to initiate and terminate such migrations are critically important for tracking favorable environmental conditions. Cues from the social environment are thought to be important for making these types of migratory decisions, yet relatively few studies have focused on understanding the significance of social cues in the context of migration. Here, we use an experimental approach to understand the use of social cues for timing the termination of vernal migration in a captive population of pine siskins (*Pinus spinus*), a nomadic migratory songbird. Specifically, during the vernal migratory period, we measured the nocturnal activity levels (i.e., zugunruhe), body condition, and reproductive development of pine siskins experiencing three different social environments. Individuals were either visually isolated from other birds, visually paired with two same-sex individuals in a neighboring cage, or visually paired with two photo-advanced, same-sex individuals in a neighboring cage. Photo-advanced birds experienced 18-hour day lengths for 1 month prior to pairing while all other birds in the experiment experienced naturally changing vernal photoperiods. We will present results describing changes in a suite of traits indicative of the transition from a migratory state to settlement and breeding including: nocturnal activity levels, body condition, and reproductive condition. By determining if these migratory traits depend upon an individual's social environment, this study will broaden our understanding of the extent to which animals use social cues to make key migratory decisions.

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16-1 Vernasco, BJ*; Dakin, R; Majer, AD; Haussmann, MF; Ryder, TB; Moore, IT; Washington State University, Carleton University, Bucknell University, Bucknell University, Bird Conservancy of the Rockies, Virginia Tech; *ben.vernasco@wsu.edu*

A telomeric perspective on the (anti-)aging phenotype of male wire-tailed manakins (Pipra filicauda)

Telomeres are considered molecular markers of biological age as telomere lengths vary with longevity inter- and intra-specifically and telomere dynamics depend upon various intrinsic and extrinsic factors. Telomeres have therefore been used to understand how different life histories relate to patterns of biological aging, though such studies are often hindered by the challenges of re-sampling free-living individuals. Here, we examine the longitudinal dynamics of telomeres in a free-living population of male wire-tailed manakins to understand how the atypical life history of wire-tailed manakins is related to patterns of biological aging. Wire-tailed manakins are passerine birds found in the Amazon and males exhibit colorful plumages, elaborate lekking behaviors, and fruit-rich diets. Males also have high annual survival rates (annual survival probability = 0.71-0.79) and remarkably long lifespan for their size (average lifespan +/- 1 SD = 8.41 +/- 2.8 years, max lifespan = 16+ years, adult male mass = 13 to 15 grams). We use 187 telomere measurements from 53 males to quantify the repeatability (i.e., a measure of within-individual consistency) of telomere lengths, test for instances of telomere elongation, and examine age-dependent changes in telomere lengths, both within- and between-individuals. The telomeres of male wire-tailed manakins were found to be highly stable and did not depend on an individual's age or social status. Telomere elongation that exceeded residual error was also found to occur very infrequently. We discuss our results in the context of the unique life-history of this species and compare our results to patterns observed in other animals.

BSP-4-4 Verstraete, CJ*; Leys, SP; University of Alberta, Edmonton, AB; *cverstra@ualberta.ca*

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Development of the amphiblastula of the calcareous sponge Sycon coactum

Calcareous sponges develop in an unusual way. The embryo forms with internally facing cilia and turns inside out to produce the amphiblastula larva, with locomotory cilia directed outwards. The larva invaginates at metamorphosis, in a gastrulation-like manner, to form the juvenile sponge. Why these events happen has fascinated biologists for over a Century without resolution. We have been able to trace the movements of cytoplasmic determinants that mark the essential larval photoreceptor determinants through development. These shift from the oocyte to four blastomeres and then into four presumptive photoreceptor cells - the cross cells – in the larva whose positioning is critical to the behaviour and successful metamorphosis of the juvenile sponge. A metanalysis of genes expressed during the development of the genus *Sycon* shows while a range of genes do mark the cross cells once they have differentiated, few genes solely mark the oocyte and are carried through to the cross cells. Of those members of the Wnt pathway stand out as also having a highly polarized expression in both larva and adult. Our findings suggest that these cytoplasmic regions are markers of polarity that is maintained from oocyte through to the juvenile sponge by way of the type of cleavage divisions, and also by inversion of the embryo and invagination of the larva at metamorphosis. We consider whether the retention/preservation of polarity and precise positioning of cytoplasmic determinants during development of these sponges may be the equivalent of forming "germ layers" in other metazoans.

47-8 Vetrova, AA*; Bagaeva, TS; Saidova, AA; Kupaeva, DM; Kraus, YA; Kremnyov, SV; Institute of Developmental Biology RAS, Moscow, University of Vienna, Vienna, Moscow State University, Moscow, Moscow State University, Moscow; *lalavetrova@gmail.com*

Apolar mode of gastrulation leads to the formation of polarized larva in a marine hydroid, Dynamena pumila

In cnidarians, canonical Wnt (cWnt) signaling patterns the primary oral-aboral body axis and controls oral identity during larval body plan formation. In many cnidarians, it also specifies a single region of gastrulation morphogenetic movements, and embryo morphology is coupled with axial molecular patterning throughout

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so-called polar gastrulation. But in numerous hydrozoan cnidarians, no morphological landmarks indicate an embryonic polarity during gastrulation. The question remains whether c Wnt signaling controls morphogenetic processes involved in apolar gastrulation. We focused on the embryonic development of *Dynamena pumila*, the hydrozoan species with apolar gastrulation. In *D. pumila*, gastrulation proceeds as a peculiar variation of mixed delamination. We revealed that the first signs of morphological polarity appear only after the end of gastrulation. However, molecular prepatterning of the embryo does exist. *In situ* analyses of oral markers Wnt3, Axin, and TCF demonstrated that a region of cWnt activity exists in the middle of gastrulation, although the exact direction of the primary body axis is not determined yet. We have shown experimentally that molecular axial patterning is highly robust in *D. pumila*. Our results suggest that morphogenetic processes are uncoupled from molecular axial polarity until the late gastrula stage in *D. pumila*. Investigation of *D. pumila* might significantly expand understanding, how morphological polarization and axial molecular patterning are linked in Metazoa. The work is supported by RFBR, 20-04-00978a.

38-7 Vidal-Garcia, M*; Marcé-Nogué, J; Marchini, M; Fortuny, J; Semple, TL; Cooper, P; Keogh, JS; The Australian National University, Canberra, Australia & University of Calgary, Calgary, Canada, Universitat Rovira i Virgili, Tarragona, Spain, University of Calgary, Calgary, Canada, Institut Català de Paleontologia Miquel Crusafont, Barcelona, Spain, The Australian National University, Canberra, Australia; *marta.vidalga@gmail.com*

Biomechanics and morphological patterns in head-first burrowing frogs

Southwest Australia is a biodiversity and endemism hotspot for herpetofauna. Three unusual Australo-Papuan myobatrachid species occur in sandy habitats across semi-arid and arid regions in the Southwest corner, and differ from most other burrowing frogs by burrowing head-first in a forward direction, a behaviour which appears to have resulted in extreme morphological adaptations. Interestingly, the degree of morphological adaptations and fossoriality varies among them, but they are all starkly different from their non-burrowing sister species. Using diffusible iodine-

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based contrast-enhanced Computed Tomography (diceCT) we were able to extract data of both bones and soft tissue of forward burrowers and non-burrowers to assess morphological adaptation to burrowing across a fossoriality gradient. We used 3D geometric morphometric analyses to identify morphological integration patterns among fore-limb bones. We also assessed 3D muscle architecture associated with forward burrowing behavior. Finally, using Finite Element Analyses we assessed the biomechanical properties of the humerus and radioulna. We discuss their morphological evolution, biomechanics, and soft tissue differences in the context of different soil properties and paleoclimatic events that might have contributed to the morphological adaptations for a fossorial lifestyle in this clade of bizarre frogs. We hypothesize that our results could help to infer behavioural and ecological habits of extinct taxa.

79-8 Vijayan, S*; Somanathan, H; Indian Institute of Science Education and Research
Thiruvananthapuram; *sajeshksv17@iisertvm.ac.in*

Stay or leave? Answers from migratory waggle dances in natural colonies of Apis dorsata

The waggle dance behaviour is a conserved mechanism in honey bees which is used to transfer information about the spatial location of resources to hive-mates. Studies which have been carried out on the Western honey bees and the tropical species of dwarf and giant honey bees have shown that swarming events in artificial swarms are preceded by waggle dances where the different waggle runs within individual dances show high variation in the distance signalled. These dances with high intra-dance variation in duration have been termed as migratory dances. Earlier studies looking at this behaviour have employed artificially generated swarms where the colonies had no choice but to migrate immediately. We revisit migratory waggle dances by decoding the dances from colonies of the giant honey bee *Apis dorsata* across two habitats in South India. We show here that migratory dances are not a sufficient indicator of ensuing migration. We conclude that these dances may serve more than one purpose, and are possibly part of a larger response of honey bee colonies towards environmental stress. Moreover, the presence of floral resources all year round, such as in urban green

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spaces, can potentially delay migration in *A. dorsata*, making this a flexible response to resource availability.

25-11 Villacís Núñez, CN*; Cooper, KL; Moore, TY; University of Michigan, University of California, San Diego; *carlanvn@umich.edu*
Fusion reinforces metatarsals and facilitates larger body sizes in jerboas (Dipodidae)
The transition from quadrupedal to bipedal locomotion involves a shift in the magnitude and concentration of ground reaction forces (GRF). As the most derived and taxonomically rich group of bipedal rodents, jerboas (family Dipodidae) are a model system for examining the functional morphological response to this shift in a phylogenetic context. Previous studies reveal that quadrupedal rodents vary in body size, but facultatively bipedal rodents (*Napeozapus sp.*, *Zapus sp.*) and early diverging bipedal jerboas (*Cardiocranius sp.*, *Salpingotus sp.*) are small. Body size increase in bipedal jerboas correlates with fusion of the central three metatarsals into a single cannon bone. We hypothesize that fusion structurally reinforces the hind foot to accommodate the higher GRF necessary for bipedal hopping. We analyzed micro-CT scans from five species in Dipodidae that span the extant size range. We standardized metatarsal length and cortical thickness. Using Finite Element Analysis, we modeled a dynamic collision between jerboa metatarsals and a flat plate representing the substrate, using experimentally measured parameters. The area of greatest stress spread across the dorsal surface of the unfused central metatarsus, taking up half of the length and all of the width. With fusion, the area of greatest stress is significantly smaller. Our results suggest that unfused metatarsals of facultatively bipedal and early diverging bipedal rodents likely presented a biomechanical constraint, limiting the body size to reduce overall GRF, which was gradually lifted as fusion evolved. Other animals with fused metapodials, such as horses and chickens, may have also experienced selective pressures favoring structural reinforcement.

65-1 Villanueva, I*; Di Santo, V; Stockholm University, Stockholm, Sweden; *villanueva.irene1996@gmail.com*

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Ontogenetic behavior of a tropical shark under future ocean acidification scenarios
Ocean acidification is considered one of the biggest threats to marine biodiversity. Some studies quantified sensitivity to acidification in embryos of teleost fishes, however, we have little insight into the consequences of high pCO_2 levels on elasmobranchs embryos. Oviparous elasmobranchs may be particularly vulnerable to elevated pCO_2 as their embryonic development is relatively slow and they may be exposed to acidic conditions for a prolonged period of time before they hatch. Even though several studies showed impairment in fish behavior across major life stages, there is still a need to quantify fine-temporal shifts in behavior and metabolism throughout development. We present a detailed timeline of the prolonged effects of ocean acidification throughout the development of a tropical shark, the brown-banded bamboo shark (*Chiloscyllium punctatum*), reared under current and projected scenarios of ocean acidification for years 2100 and 2300 (approx. pCO_2 = 1100 and 2000 µatm, respectively). In particular, we present data on the effects of ocean acidification on embryonic metabolic rates at rest and during activity, general behavior and activity over time, ventilation rates, and tail beat frequency (Hz) taken across the developmental period. Additionally, we focus on important milestones in the development of bamboo sharks such as the formation of gill filaments, fins, and skin pigmentation. This study is crucial to obtain a deeper understanding of elasmobranch vulnerability to future ocean acidification during early life stages.

28-3 Villegas, M*; Hobson , KA; Soos, C; Jiménez-Uzcátegui, G; University of Saskatchewan and Environment and Climate Change Canada, Saskatoon, SK, Canada, University of Western Ontario, London, ON and Environment and Climate Change Canada, Saskatoon, SK, Canada, Estación Biológica Charles Darwin, Puerto Ayora, Galápagos, Ecuador; *mariana.villegas@gmail.com*
Interspecific isotopic niche differentiation among Darwin's finches in Santa Cruz Island, Galápagos
Darwin's Finches on the Galápagos Islands are a classic example of adaptive radiation and ecological segregation. Here we build upon this extensive foundation by using stable isotope analyses of

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feathers to examine the isotopic niche and trophic segregation among Darwin's finches. We analyzed stable carbon, nitrogen and hydrogen values (δ13C, δ15N and δ2H) in wing secondary coverts from live birds (sampled in 2019) and museum specimens belonging to eight Darwin's finch species from Santa Cruz Island. Insectivorous finches had higher δ15N and δ2H values and lower δ13C values compared to other guilds. Herbivorous finches had the largest isotopic niche followed by granivorous finches and lastly by insectivorous finches; although there was considerable overlap among guilds. Analyses proposed by Rossman et al. (2016), allowing for the use of three stable isotope dimensions, showed that when adding δ2H values in the description of trophic niche, insectivorous finches differentiate better from the other guilds. There was a significant difference in isotope values among habitats (i.e. dry, transition, humid zones and farms) only for δ13C values. Our study shows that even though some species are categorized to one guild (e.g., granivorous or insectivorous), dietary generalist species (those with a wide range of δ13C and δ15N values) dominate the bird community. Our results on isotope data indicate a greater dietary and ecological overlap among Darwin's finches than previously described, especially among ground finches.

81-1 Virdi, S*; Sane, S P; National Centre for Biological Sciences, Tata Institute of Fundamental Research, Bengaluru, India; *simranv@ncbs.res.in*

Morphology and neuroanatomy of the femoral chordotonal organ in the Oleander hawkmoth, Daphnis nerii

Insects sense their own body movements as well as external perturbations via proprioceptive feedback. In particular, the Femoral Chordotonal organ (FeCO), which is embedded in their legs, senses the femoro-tibial joint movements. Extension of the joint stretches and activates these mechanosensors, whereas joint flexion relaxes them. FeCO is an integral part of local sensori-motor feedback loops which control many leg behaviours, including posture maintenance and walking. To characterize the role of FeCO in flight initiation, we developed an assay in which a quick removal of removal of the substrate from legs initiated rapid flight response in the Oleander hawkmoth, *Daphnis nerii*. This so-called 'tarsal

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reflex' causes rapid initiation of flight, completely bypassing the preparatory 'warm up' phase of flight initiation which can take up to a minute. To explain this fast response, we hypothesized that the neural projections of FeCO to colocalize with the flight motoneuron arbors in the thoracic ganglia. We therefore filled sensory and motor neurons with fluorescent dyes and imaged whole mounts using confocal microscopy. We also characterized the morphology and neuroanatomy of the FeCO in *Daphnis nerii*, after identifying its location at the proximal end of the femur. Phalloidin stains of FeCO revealed the number of scolopidial units broadly organized into 2 subunits. These data lay the groundwork for future physiological investigation of the femoral chordotonal organs in hawkmoths.

14-1 Vo, K*; Amaya, M; Stankowich, T; California State University, Long Beach; *kvokathy@gmail.com*

Potential risk factors that influence pet predation by coyotes

Coyotes are well-adapted to living in close proximity to humans and entering urban spaces, presenting an ongoing issue of human-wildlife conflict as concerned pet owners push for extreme measures to keep their pets safe. In this community outreach study, we distributed an online survey open to the public to report data on previously or currently owned cats and dogs including size, breed, fur coloration, amount of time spent outdoors, and interactions with coyotes. Reports from 1301 dogs showed that smaller dogs, dogs that spend more time outdoors daily, and dogs with low fur color contrast experience more severe interactions with coyotes. This finding lends support to our hypothesis that coyotes may generalize their learned avoidance of skunks to also hesitate to attack domestic pets with similarly high fur color contrast. We did not find any effect of pelage color contrast or time spent outdoors on the severity of coyote interactions in the reports from 590 cats. We propose that, unlike cats, (a) the greater tendency for dogs to defend themselves aggressively against other canids paired with (b) high contrast coat color patterns, may trigger coyotes' learned aposematic avoidance of skunks, and give black-and-white dogs a greater chance of survival. In improving our understanding of why coyotes target some pets and not others, we hope to inform pet

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owners of potential risk factors that may make their pets more vulnerable to coyote attacks.

S6-3 Vo-Doan, TT; Straw, AD*; University of Freiburg; *straw@bio.uni-freiburg.de*

Videography using a fast lock on, gimbal-mounted tracking camera to study animal communication

Video is a key data source for quantitative analysis of animal communication behaviors. Nevertheless, the limited spatial-temporal resolution of video makes it difficult to record images in which detailed pose information can be extracted while an animal moves over a large volume. The demands of high spatial and temporal resolution of the subject conflict with obtaining a large recording volume due to limited pixel counts and framerates of cameras. This problem is particularly pronounced in animals, such as flying insects, which travel rapidly over meters but whose body is orders of magnitude smaller. To address this issue, we have developed a fast lock on system which keeps a moving insect "locked" in the field of view of a high-resolution camera by continuously keeping the camera aimed at the insect as it moves. This is achieved by marking the animal with a small reflector which is illuminated and imaged with an additional optical system to the video camera. Both systems share the optical axis which can be aimed using a fast gimbal. This additional system consists of an illumination laser, focusing optics, and a quadrant photo diode. Electrical signals from the photo diode array are used to command the gimbal such that the image of the reflector is centered. By using electrical signal processing, the system is faster, cheaper and simpler than related solutions based on digital image processing, at the cost of decreased flexibility. Using this system, we have made lab-based videos of locusts and beetles in which legs and antennae remain in sharp focus even as the animal jumps and flies. We believe this technology will be useful in the study of animal communication, especially when combined with techniques such as automatic pose extraction from the recorded video.

7-2 Vollin, MF*; Higham, TE; University of California, Riverside; *mvoll002@ucr.edu*

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The effect of tail autotomy on prey capture performance in Coleonyx variegatus geckos
Anti-predator adaptations often incur negative consequences for the prey organism. A particularly dramatic example is autotomy, the voluntary severance of an appendage in response to a variety of pressures, including predation and intraspecific competition. Tail autotomy in lizards has been linked to lower reproduction, slower locomotion, instability during jumping, and decreased social status, but the effect of tail autotomy on prey capture ability has not been unexplored. Desert banded geckos (*Coleonyx variegatus*) undulate their tails immediately prior to striking their prey. Additionally, they frequently capture evasive prey in nature. However, it is unclear if these tail movements are important for the strike itself, or if they simply draw attention to that part of the body. We used high-speed 3D videography to quantify prey capture performance of *C. variegatus* geckos striking at crickets before and after total caudal autotomy. We tested performance within two hours of autotomy and then repeatedly over a two-week period. Overall prey capture success was unaffected by caudal autotomy. However, maximum strike velocity significantly dropped immediately after autotomy (after two hours) but increased back to pre-autotomy conditions after two weeks. This not only highlights the importance of the tail during prey capture, but also suggests that geckos eventually develop compensatory mechanisms to deal with the loss of the tail. Our analyses will also examine the changes to limb and body kinematics as a result of tail autotomy.

41-7 Voltzow, J*; Karpiak, CP; Mulhall, D; Muir, S; University of Scranton, PA; *janice.voltzow@scranton.edu*
Royal Scholars: An NSF S-STEM program to support science identity in low-income STEM students in Pennsylvania
Supported by a grant from the National Science Foundation's Scholarships in Science, Technology, Engineering, and Mathematics (S-STEM) program, the Royal Scholars program at The University of Scranton provides scholarships for local, low-income students who have demonstrated academic ability or potential in STEM. The goals of the program are to assist students in developing their identities as STEM professionals, exploring careers in STEM, and taking steps along the appropriate pathways to these careers to

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improve the STEM workforce. The program recruits cohorts of freshmen and juniors who receive support throughout their time at Scranton. All students attend a weekly seminar course that focuses on building a sense of community and STEM identity. Students are required to complete an independent project before they graduate. We have had 100% retention in this program. In spring 2020 our first cohort of seniors plus one junior graduated. A survey of the students in the program indicates that they have strengthened their STEM identities and agreed that hearing from STEM professionals gave them confidence in pursuing a STEM career. Assessments so far indicate that participation in the program is having a positive impact. All graduates acknowledged that the program contributed to their success as STEM students.

100-2 Wade, KL*; Pradhan, DS; Grober, MS; Idaho State University, Biological Sciences, Pocatello, Idaho, Georgia State University, Department of Biology, Atlanta, Georgi; *kristinawade@isu.edu*
Female social status, morphology and endocrinology in a hermaphroditic fish
During the breeding season, a number of factors can affect female hormone levels. These include cyclical changes in ovarian hormones, nutrition, mate availability, and interactions among conspecifics. This study examines the effects of female social status on morphological traits and steroid levels in the brain and ovarian tissue of a hermaphroditic fish, the bluebanded goby, *Lythrypnus dalli*. In these fish, the male dominates the social hierarchy, which consists of a harem of females that compete for opportunities to reproduce. Here, we maintained social groups (n=34) consisting of one male and two size mismatched females for 4 weeks. The alpha female was subordinate to the male, but maintained a higher social status compared to the beta female. Alpha females had significantly higher standard length, body mass, and ovarian score compared to beta females. Overall, female status did not affect reproductive maturity, but there were differences based on ovarian stages. While levels of 11-ketotestosterone, testosterone, and cortisol in the brain were significantly higher in beta females compared to alpha females, levels of 17β-estradiol in the ovary was significantly higher in alpha females compared to beta females. Tissue hormone

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levels in females can be used to evaluate endocrine mechanisms that regulate reproductive physiology and behavior.

48-2 Wagner, W; Smithsonian Institution; *wagnerw@si.edu*
Vicki Ann Funk (1947-2019), influential Smithsonian botanist
Vicki A. Funk was one of the most active, enthusiastic, and passionate botanists of our time. She had a quick mind and wit, always with new ideas or opinions that she eagerly shared with anyone who would listen and engage. She treated everyone equally and found pleasure in insights that she gained by interacting with others. Vicki was generous in sharing ideas that not only produced successful research and training, but also created comradery. She was regarded for her productivity and for pioneering the use of phylogenetic methods. Her primary expertise was the sunflower family, and she made 15,000 collections. She was passionate about development of herbaria. She published 320 articles and books, including Systematics, Evolution, and Biogeography of the Compositae (2009), the most authoritative reference for the family. She was a pioneering influence in the use and development of phylogenetic methods (e.g., Advances in cladistics, Funk & Brooks 1981; Platnick & Funk 1983; Hawaiian Biogeography, Wagner & Funk 1995). Vicki was an outstanding leader, and served as president of biological societies (SSB, 1998-1999, ASPT, 2006-2007, and IAPT, 2011-2017), and as a founder and president of the IBS (2007-2009). Vicki and colleagues founded "The International Compositae Alliance," fostering work in the family. Within the Smithsonian, she served as Director of the Biological Diversity of the Guianas (1987–2018), but also began the Global Genome Initiative for Gardens (2015–2018). Most recently, she was an advisor to the American Woman's History Initiative, focusing on the contributions of women in science as part of the broader effort to disseminate the historical record of accomplishments of women. Vicki was an exemplary mentor from advising undergraduate interns to mentoring current faculty. She actively mentored more than 40 students, early career colleagues and was an unofficial mentor to many others.

57-11 Wagner, G*; Morgan, N; Yen, J; Georgia

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Tech; *griffin.wagner@gatech.edu*

Attack of the killer copepod

Hesperodiaptomus shoshone is a large freshwater alpine [10,000 ft] copepod whose behavior has been studied for their response to UV radiation at high elevation [Williamson] and for their ability to use mechanoreception to sense water flows generated by their female mates [Yen]. Analyses of their feeding habits show that they are voracious predators on 2 cladocerans, Moina and Daphnia. Maximum feeding rates on the small cladoceran Moina [0.5 mm] were 40 prey /day at a concentration of 60 prey/125 mL while maximum feeding rates on the larger more active cladoceran, juvenile Daphnia [0.8 mm] was 12 prey /day at 40 prey/125 mL. High speed 3D video observations -aimed at mapping the 3D attack volume- showed that *Hesperos easily captured and retained Moina but had a hard time maintaining a good grasp on the more robust Daphnia. The odd behavior was when satiated, Hesperos continued to kill Moina and juvenile Daphnia but left behind uneaten carcasses. Starved predators did not leave fewer carcasses than fed predators. Hesperos continued to feed on carcasses, indicating that movement of the prey was not necessary for detection, capture, and ingestion. We continue experiments to understand why Hesperos kills excess prey that they do not eat.*

22-10 Wainwright, DK*; Lauder, GV; Yale University, Harvard University; *dylan.wainwright@gmail.com*

The surfaces of sharks and bony fishes: a comparison of scale structure and function

Small mineralized structures called scales cover the surfaces of sharks and bony fishes, yet this common term belies an abundant diversity of forms. Shark scales are highly three-dimensional and protrude outwards from the epidermis, ending in swept-back heads that point towards the tail. In contrast, bony fish scales are typically flat embedded plates that overlap considerably with neighboring scales so that just their trailing-edges are free. Here we briefly summarize our work on the morphology of these two surfaces, and we end by discussing future work to examine the hydrodynamic function of shark and bony fish surfaces. Our work uses profilometry and three-dimensional imaging techniques to understand the topography of shark and bony fish surfaces, which

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provides a quantitative method for comparing surfaces, leading to observations on shared patterns across taxa. For example, shark and bony fish surfaces both exhibit a range of roughness, but shark surfaces tend to have negative skew values, reflecting the relative prominence of valleys and other negative features in their surfaces. In contrast, bony fishes often have positive skew values, indicating the relative prominence of hills and positive surface features. We show how shark scales change in morphology from large feature-less scales on leading-edge surfaces to small highly-overlapping scales on trailing edge surfaces, and we contrast this with bony fishes, that tend to lack scales on their heads but often have only subtle difference in scale morphology down the body. We end by assessing future directions on how the surfaces of sharks and bony fishes behave in flow - in particular we share how mucus may play a role on fish surfaces and how we might begin to link scale morphology and hydrodynamics in sharks.

33-8 Walker, NS*; Palumbi, SR; Stanford University, Hopkins Marine Station; *niasw@stanford.edu*

Do high heat resistant corals have lower recovery rates from bleaching?

Global coral bleaching has focused attention on interventions to increase heat resistance. However, a key feature of climate resilience is the ability to recover from bleaching–as well as resist it. Here, we tested individual *Acropora hyacinthus* colonies' heat resistance and recovery capabilities. We subjected 27 colonies, found in Palau, to acute heat stress until they moderately bleached (~50% symbiont reduction). These colonies were then split into low, moderate, and high resistance categories based on number of days to bleach and transferred back to the reef via a common garden. We measured recoverability on the order of weeks to 4 months post-heat stress. As expected, mortality was highest among low resistant colonies (60%) and lowest in high resistant colonies (30%). However, our current data show a dramatic result: after experiencing the same level of bleaching, moderately resistant corals grew the fastest. Moderately resistant corals grew 4 times faster than the highest and lowest resistant corals. The best future corals may have moderate resistance and higher recoverability. These results suggest that high heat resistance may

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come along with a tradeoff in growth potential that changes how reefs are viewed and managed. It may be critical to better understand resilience to improve long-term conservation initiatives.

BSP-8-3 Walkowski, WG*; Santana, A; Gaston, T; Gordon, WC; Bazan, NG; Farris, H; Louisiana State University Health Sciences Center; *wwalko@lsuhsc.edu*

Endocrine modulation of retinal sensitivity in Hyla cinerea

Many behavior patterns that are strongly modulated by hormones, such as mate choice, are mediated by vision. Yet, little is known about the effect of reproductive hormones on the retina, which is critical to understanding how visual signals are processed during these behaviors. This project examined the effects of reproductive status on retinal spectral sensitivity or the ability to detect different wavelengths associated with visual signals. Our hypothesis is that hormones modulate stimulus sensitivity in the retina during reproductively receptive phases, ultimately influencing mate choice behavior through modulation of color vision. We tested the effect that hormones have on color vision using the green treefrogs (*Hyla cinerea*), which detect and respond to wavelengths spanning (and beyond) the human visible light spectrum. Experiments used electroretinograms (ERGs) to compare stimulus threshold and response amplitude in the retina of reproductive and non-reproductive female frogs. Additionally, we compared retinal activation before and after treatment with exogenous hormones. Our findings indicated that for females reproductive state and hormone injections cause an increase in spectral sensitivity to particular ranges of wavelengths. These results supprt the potential for functional consequences of endocrine modulation on particular visual signal components used during mate choice.

BSP-8-4 Wallace, KJ*; Hofmann, HA; The University of Texas at Austin; *kwallace@utexas.edu*

Decision-making in a social world: sex and status differences in cognition in the cichlid fish Astatotilapia burtoni

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Individual variation in behavior and cognition is underpinned by variation in neural decision-making mechanisms, which are subject to the varied ecological pressures individuals experience. The highly social African cichlid fish *Astatotilapia burtoni* forms dynamic dominance hierarchies where males transition between dominant (colorful, aggressive, territorial) and subordinate (reproductively repressed, non-territorial) phenotypes. Social ascent in this species induces a cascade of rapid behavioral, physiological, and neuromolecular changes. *A. burtoni* displays complex cognition that allows both males and females to navigate this fast-paced social world. Here, we ask whether social ascent affects cognitive performance and/or the behaviors exhibited during cognitive tasks. Because systematic cognitive testing has not been done in this species, we first assessed males and females in two cognitive tasks: a novel object recognition task and a spatial task. We found that novel object preference and likelihood to meet the spatial task learning differed between the sexes. Furthermore, the sexes differed in space use in both tasks, and multivariate analyses uncovered relationships between behavior, age, and sex both within and across tasks. Next, we perturbed each community in a manner that provided males with the opportunity to ascend in status and subsequently subjected them to the two tasks described above. This allowed us to compare cognitive performance and behavior across timepoints of social ascent. Ongoing work examines the neuromolecular mechanisms that integrate social behavior and cognition. This work highlights the need to explicitly test across multiple tasks and social contexts to better understand how individuals make decisions in dynamic social environments.

9-4 Wang, L-Y*; Franklin, AM; Black, JR; Stuart-Fox, D; The University of Melbourne, School of Biosciences, Australia, The University of Melbourne, School of Earth Sciences, Australia; *luyi.wang@student.unimelb.edu.au*

Heating rates in jewel beetles are more strongly influenced by near-infrared than visible reflectance

Color variation in ectotherms is influenced by selection for multiple functions including thermal benefits. Thermal effects depend on the integument reflectivity across the full spectrum of sunlight, including ultraviolet (UV), visible (VIS), and near

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infrared (NIR); but the latter is rarely considered. Here, we examined the relative contribution of UV-VIS and NIR reflectivity to radiative heat gain for 17 species of jewel beetles (Buprestidae) that vary in the reflectivity of the elytra. We measured the heating rate of the elytra using a solar simulator and a thermal chamber to control the effect of conduction and convection, and optical filters to isolate the effect of UV-VIS and NIR reflectivity. We also investigated the effect of other cuticle properties, namely surface area, thickness, and surface rugosity. We found that reflectivity predicted heating rate and this was driven by the variation in NIR rather than UV-VIS reflectivity. Surface area had a weak effect on heating rate, whereas cuticle thickness and surface rugosity had no detectable effect. Heating rate of isolated elytra corresponds to differences between species in heating rate of whole beetles measured with the same method. Taken together, our results suggest that the reflectivity of elytra has an important effect on radiative heat gain in jewel beetles and highlights the potential role of NIR reflectivity in thermoregulation. NIR reflectivity may be particularly important for thermoregulation because it is free from selection for visual functions such as camouflage or communication.

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Regeneration enhancers and the uneven distribution of regenerative capacities in vertebrates

Species such as bony fishes display extensive regenerative capacities, while others such as mammals regenerate poorly. The mechanisms underlying the broad disparity of regenerative capacities in animals remains elusive. Here we report on a comparative epigenomic and transcriptomic approach which identified an evolutionarily conserved regeneration response program (RRP) in vertebrates. By defining the cis-regulomes and transcriptomes of early stages of regeneration in the distantly related zebrafish Danio rerio and the African killifish Nothobranchius furzeri, we were able to discriminate between species-specific and evolutionarily conserved genomic responses to amputation. Importantly, functional testing by systematic transgenic reporter assays of the conserved inhibin beta A (inhba) regeneration

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responsive enhancer (RRE) from zebrafish, killifish, and humans identified species-specific variations. Furthermore, deletion of the killifish inhba RRE significantly perturbed caudal fin regeneration and completely abrogated cardiac regeneration. We also show that inhba RRE activity requires the presence of predicted binding motifs for the Activator Protein 1 (AP-1) complex. Interestingly, AP-1 binding motifs can be identified in the conserved and non-conserved teleost RREs reported in this study, indicating that AP-1 may be required for both injury and regeneration responses. We propose that changes in RREs driven by natural selection are likely a crucial source of loss of regenerative capacities in vertebrates, including humans.

24-2 Wang, S*; Zhao, W; Wainwright, DK; Xu, H; Li, L; Sun, W; Wen, L; Beihang University, Yale University; *liwen@buaa.edu.cn*

An untethered remora-inspired suckerfish robot: locomotor effects of the disc pad, undulatory body, and pectoral fins

Remora (Echeneis naucrates) can rapidly switch between swimming and attachment on a variety of marine hosts. We know that these maneuvers are performed by the dorsal suction disc, the flexible body/caudal fin, and the pectoral fins, but the specific effects of these components' on attachment and detachment performance remains poorly understood. To remedy this, we collected data on remora morphology, and we studied the kinematics of the remora suction disc, fish body, and pectoral fins during attachment and detachment using two synchronized high-speed cameras. Based on these biological data, we developed an untethered biomimetic robotic remora suckerfish with an overall size of 45 x 25 x 10cm (L*W*H). This robot comprises three parts: 1) a biomimetic suction disc that aligns the disc to the surface, 2) a flexible fish body with mobility in both lateral and dorsal-ventral directions, and 3) a pair of flexible pectoral fins that can both flap and pitch. The fish body and pectoral fin were actuated by one brushless DC motor and seven servo motors. Utilizing the biomimetic robotic remora, we examined the undulatory amplitude/frequency of the caudal fin and the pectoral fins on the preload of the adhesive disc. We also investigated the effects of the head's pitch motion on the attachment and detachment performance of the robot. This study may shed light on the biomechanics of dynamic adhesion and paves a way

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to the next generation of remora-like bio-robotic systems for real-world applications.

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Uncovering the role of head flexion during beam obstacle traversal of cockroaches

Terrestrial animals transition between locomotor modes to move through complex 3-D terrain. For example, to traverse grass-like beam obstacles, the discoid cockroach often transitions from pushing across the beams with body pitching (the pitch mode) to rolling into a beam gap (the roll mode). Our recent study (Othayoth, Thoms, Li, 2020, *PNAS*) discovered that kinetic energy fluctuation of body oscillation due to self-propulsion helps a robotic physical model overcome a barrier on a potential energy landscape to make pitch-to-roll transition. Although the animal also displayed substantial kinetic energy fluctuation, it was not sufficient to explain the observed pitch-to-roll transition. Besides body oscillation, during beam interaction the animal also flexed its head and abdomen and used its left and right hind legs differentially (Wang, Othayoth, Li, 2019, *SICB*). Here, we hypothesized that head and body flexion reduces the pitch-to-roll transition barrier. To test this, we measured the animal's head and abdomen flexion (N = 3 individuals, n = 36 trials) and modeled how they changed the potential energy landscape reconstructed from the measured body and beam motions. However, we found that pitch-to-roll barrier did not change significantly with head and abdomen flexion ($P > 0.05$, ANOVA). Alternatively, the animal may be flexing its head against the obstacles to feel their resistance and use this information to guide abdomen and leg motions to facilitate transition. To study this, we developed a new robot with an actuated head and abdomen that can flex and a force sensor in the head to measure terrain contact forces. The robot also has underactuated body pitch and roll control to simulate the effect of legs. We are developing sensory feedback control and will use the robot to perform systematic experiments.

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Effect of motivation on sequential jump strategy in fox squirrels

Fox squirrels perform incredibly agile feats of saltatorial locomotion. Parameters that squirrels use to make biomechanical decisions when negotiating challenging, complex arboreal terrain remain uncertain. We tested the hypothesis that jump strategy depends on trade-offs of motivation versus falling risk. We trained six free-ranging fox squirrels to leap between three horizontal rods perpendicular to the path of motion at a 1.5m height with modifiable gaps of 0.50m, 0.75m, or 1.00m. We recorded 329 trials for 3D kinematics using 12 high-speed cameras. We observed two distinct jumping strategies: rapid, continuous jumps where squirrels did not stop on the center rod versus slow, discontinuous jumps with pauses on the center rod before conducting the second jump. We tested the hypothesis that discontinuous jumps with a low failure rate would be favored if the reward (peanut) outweighed the perceived risk of pausing. Squirrels only chose continuous escape jumps because they perceived a greater risk of pausing. Rapid, continuous jumps with a higher failure probability were only made at 0.50m and 0.75m increments. During rapid jumps at 0.75m, squirrels had a 10% greater mid-jump spine bending angle. They landed on the middle rod with a 35% larger landing angle, allowing for a rapid transfer of momentum into horizontal velocity during the second jump. While squirrels were quite adept at jumping, their risk of missing the rod with their hind legs increased significantly from 3% to 41% when we increased distances to 1.00m. Squirrels never entirely missed rods, but would often only grasp with their front feet. Squirrels’ cognitive decisions that include motivation and risk play a critical role in determining their biomechanical jump strategy.

92-3 Warner, DA*; Pruett, JE; Fargevieille, A; Klabacka, RL; Auburn University; *daw0036@auburn.edu*

Do female lizards choose nest sites based on the predictability of substrate moisture?

Nesting behavior is an important part of reproduction that affects the fitness of mothers and their offspring. Females of most oviparous species choose microhabitats for nesting that have

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positive effects on embryo development. However, choosing suitable nest microhabitats could be challenging in environments that fluctuate unpredictably. In many reptiles, females avoid nesting in dry microhabitats because eggs will rapidly desiccate. In nature, however, microhabitats with suitable hydric conditions at the time of oviposition may eventually become lethally dry during incubation. We hypothesize that females avoid nesting in locations with unpredictable fluctuations in substrate moisture. To test this, we provided captive brown anoles (*Anolis sagrei*) three nest conditions to choose among: 1) substrate that predictably alternated between suitable and lethal moisture conditions, 2) substrate that fluctuated unpredictably between suitable and lethal conditions, and 3) substrate with moisture levels that remained constant. For the constant choice, some females could choose moist substrate (a "safe" choice), and others could choose dry substrate (an "unsafe" choice). Females almost always nested in substrates that were moist at the time of oviposition, regardless of the level of predictability. Additionally, while constantly dry substrate was avoided, maternal choice of nest site was equally divided between the predictable and unpredictable conditions. These results suggest that nest site choice is based on immediate environmental cues, rather than the level of predictability of future conditions of nest sites.

88-8 Watson, CM*; Cox, CL; Midwestern State University, Florida International University; *charles.watson@msutexas.edu*

Temperature, oxygen, and the origins of viviparity

Previous research has supported the importance of temperature in favoring the evolution of viviparity. However, recent research with squamate reptiles (the group with the most extant evolutionary origins of viviparity among terrestrial amniotes), suggests that low oxygen availability at high elevations could also be an important factor underlying the origins of viviparity. If hypoxia favors the evolution of viviparity, then 1) hypoxia should lead to a decrease in offspring fitness, 2) gravid females should be able to provide a similar or enhanced oxygen environment compared to an egg at high elevations, and 3) females should be able to behaviorally and physiologically accommodate to increase oxygen availability to the developing embryo. By canvassing the existing

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literature, we found that eggs incubated in hypoxic environments result in embryos with reduced viability and increased frequency of developmental anomalies. Hatchlings that developed in hypoxia are also smaller which can reduce fitness. However, we found that the maternal blood environment may be normoxic relative to the environment available to eggs at high elevations. Mechanisms supporting this include increased respiration rate and hemoglobin concentration that increase oxygen availability to embryos. Viviparous females also have maternal and extraembryonic tissues that can promote enhanced vascular gas exchange between the embryonic and maternal tissues. Together, these results highlight potential physiological mechanisms whereby hypoxia could influence the evolution of viviparity.

76-7 Waybright, SA*; Dillon, ME; University of Wyoming; *swaybrig@uwyo.edu*

Do bumble bees cultivate yeast to augment protein in the larval diet?

Bumble bees and other pollinators feed on nectar and pollen, with pollen considered the primary source of protein critical for rearing young. Recent studies reveal that both nectar and pollen are replete with microbes and that bumble bees prefer yeasty nectar over yeast-free nectar. However, why bumble bees seek out yeasts is not clear. Other bees feed larvae fermented pollen, suggesting that yeast might provide additional protein to developing young. We hypothesized that bumble bees cultivate yeasts on pollen to enrich protein provisions for developing young. To test this hypothesis, we first verified active yeast growth (via a plating assay) from comb and pollen pot swabs of commercial bumble bee colonies (B. impatiens). We then determined how yeast growth on pollen affected total protein content of what would be the larval diet by inoculating sterile artificial pollen with a yeast strain isolated from comb. Yeast-inoculated pollen had a ten percent higher protein concentration than sterile pollen immediately after inoculation and two-fold higher protein after incubation in colony conditions for 24 hours, revealing dramatic effects of yeast on quality of larval food. Ongoing work will aim to determine whether this is simply a passive outcome of a ubiquitous microbe being unwittingly transported into bumble bee colonies, or whether bumble bees

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actively cultivate yeast as a high quality protein source for developing larvae.

110-6 Weaver, RJ*; Havird, JC; University of Texas at Austin; *ryan.weaver@utexas.edu*

Tight evolutionary rate correlations between mammalian mitochondrial- and nuclear-encoded aerobic respiration proteins

In most animals, mitochondrial genomes (mtDNA) evolve at a higher rate than nuclear genomes (nDNA), which sets the stage for incompatibilities between the products of the two genomes. Mitochondrial and nuclear -encoded proteins are integrated in aerobic respiration which often requires their co-functionality. These requisite mitonuclear interactions are the basis for the mitonuclear coevolution hypothesis which posits that rapid mt evolution drives compensatory nuclear evolution in genes that encode mt-interacting proteins. Although mt evolution rates vary across taxa, one signature of coevolution is coordinated variation in mitochondrial and mitochondrial-targeted nuclear-encoded proteins (n-mt) substitution rates. Here, we predicted that n-mt proteins would show correlated evolutionary rates with mt genes but that other n-encoded non mitochondrial-interacting proteins would not. Using sequences from 59 mammal species across eight orders, we found strong correlations between evolutionary rates of mt and n-mt proteins involved in oxidative phosphorylation. In contrast, evolutionary rates of nuclear proteins that do not interact with mt proteins, but also function in energy production, were only weakly correlated with mt substitution rates. In light of other recent studies that show elevated positive selection on n-mt but not other n genes, our results suggest that nuclear compensation is one mechanism by which mammals maintain mitonuclear coevolution.

51-6 Weber, A*; Guibinga Mickala, A; Ntie, S; Mickala, P; Lehmann, D; Abernethy, KA; Anthony, N; University of New Orleans, Université des Sciences et Techniques de Masuku des Sciences et Techniques de Masuku, Université des Sciences et Techniques de Masuku, Université des Sciences et Techniques de Masuku, Agence National des Parcs Nationaux, University of Stirling, CENAREST; *aweber2@uno.edu*

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Demographic history of wild mandrills during periods of climatic change in Gabon

Globally, historical environmental shifts have been shown to have had strong impacts on genetic diversity in many species, in some cases causing population bottlenecks or fragmentation. Over the millennia, Central Africa has been characterized by tumultuous environmental changes. Extreme rainforest contractions occurred during the last glacial maximum about 12,000 years before present (YBP), and during the "rainforest crisis" of 2500 YBP, which has been attributed to either climate change or anthropogenic influence. Genetic evidence from contemporary populations suggests that the resulting forest fragmentation had an important role in the evolution of modern forest-dwelling species in the region, instigating diversification and population structure. Past researchers have speculated that the apparent divergence of the northern and southern populations of mandrills (*Mandrillus sphinx*), a primate endemic to central Africa, may have been partially due to Pleistocene-era contraction of rainforests into northern and southern refugia. However, the effects of the region's changing climate on mandrill effective population size have thus far been unknown. We used microsatellite data collected from a wild mandrill population in Gabon to explore the demographic history of this species as it correlates with past environmental changes. We found no evidence that these shifts were associated with population bottlenecks in this species, suggesting that their populations historically were numerous and capable of weathering major environmental changes.

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Neural encoding and structural properties interact to determine optimal placement of sparse, spiking sensors on an insect wing

Rapid sensory feedback is necessary for executing complex movements with precision. In many flying insects, strain-sensitive structures on the wings provide an essential component of this feedback. Structural properties (e.g. wing geometry, flexural stiffness) interact with forces acting on the wing to produce the local strain sensed by the nervous system. While previous work has examined how wing structure determines aerodynamic performance, the impact of

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wing mechanics on strain sensing remains unexplored. Using a computational model inspired by the wings of the hawkmoth *Manduca sexta*, we examine how strain-sensitive sensors can be most efficiently placed over a flapping wing to detect body rotations via Coriolis force-induced strains on the wing. We modeled the transformation from strain to action potentials (spikes) using a linear filter and a nonlinear function, which were derived from prior experimental analyses of strain sensing in *Manduca*. We show that spiking sensors, conveying a signal that is both spatially and temporally sparse, can accurately detect body rotation over a wide range of wing stiffness values: typically only five sensors are needed to achieve near-peak accuracy, in many cases greater than 90%. Structural and neural encoding properties interact to jointly determine the optimal number of sensors and their locations, concentrated at either the wing base or the wing tip. Moreover, sensing performance is robust to both external disturbances and sensor loss. Our results show that small amplitude, dynamic inputs can be extracted with spatially and temporally sparse sensors in the context of flight and point to the importance of the joint evolution of structural and neural encoding properties.

47-1 Webster, NB*; Meyer, NP; Clark University; *nwebster@clarku.edu*
Nature or nurture: autonomous or conditional specification of the nervous system in spiralians
Cell fate determination during development requires a complex mix of inherited and external signaling cues. An ideal framework to examine fate determination is spiral cleavage, the ancestral form of cleavage for Spiralia (~Lophotrochozoa). Animals with spiral cleavage undergo stereotypic cell divisions, and each cell (blastomere) reproducibly produces a specific set of tissues—an ideal situation to study inherited signaling cues because cell fates are known in advance. By removing potential signaling cells we can determine if their external signals are necessary for a specific developmental fate (conditional specification). If the specific end fate is still produced, this suggests that only inherited signals are necessary (autonomous specification). Recently it was determined that the head neural tissue was autonomously specified in the sedentary annelid *Capitella teleta*. Intriguingly, trunk neural tissue was not, suggesting that the

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brain and VNC may be controlled by different and independent genetic signaling modalities. Here we used blastomere isolations to test for autonomous or conditional neural specification in the gastropod *Crepidula atrasolea* and the errant annelid *Platynereis dumerilii*. Our results will help us determine whether separate signaling modes driving head and trunk neural development is unique to *C. teleta* or is a widespread phenomenon in spiralians. If it is widespread, then this would support a deep homology in spiralian central nervous system (CNS) development. If there are differences in how neural fate is specified in these three groups, this could indicate that evolution of developmental programs in the context of the highly conserved spiral cleavage program is more labile than expected. Alternatively, this may suggest that the CNSs of these groups are not fully homologous.

9-1 Weir, SE*; Lord, NP; Louisiana State University; *sweir3@lsu.edu*
Pigment identification and quantification in the jewel beetles (Buprestidae: Stigmoderini)
Animal coloration facilitates sexual signaling, species recognition, aposematism, camouflage, and thermoregulation. In insects, structural color has been well defined, yet most pigmentary colors and their chemical composition remain unexplored. While melanins are found in numerous taxonomic groups, other pigments are taxon-specific (*e.g.*, aphins in aphids, papiliochromes in butterflies). The diverse Jewel Beetles (Coleoptera: Buprestidae; 15,000+ spp.) predominantly possess iridescent coloration achieved through multi-layer stacks of the cuticle, but a few lineages have exclusively pigmentary colors in conjunction with unique defensive compounds. This offers an ideal system in which to characterize pigment molecules, investigate cuticular morphology, and assess the role of color in an evolutionary framework. Members of the tribe Stigmoderini (Buprestinae) are equipped with buprestins, a class of toxic compounds exclusive to Buprestidae, in combination with their possibly aposematic coloration of black, brown, red, orange, and yellow. The lineage has a disjunct distribution in Australasia and Neotropics, suggesting a probable link between distinctive metabolic products and divergent evolution from Gondwana. This study aims to characterize pigment classes and types in members of

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Stigmoderini *via* solubility tests, absorbance spectrophotometry, and HPLC separation. The resultant findings will be combined with geographical and natural history data (*e.g.*, food preference) to assess evolutionary innovations such as pigment production vs. sequestration, links with larval and adult diet, and phylogenetic patterns. These data will be disseminated to currently developing color databases such as the Insect Color Database (ICDB; insectcolor.com) and PhotochemCAD (photochemcad.com) to inform future work.

64-9 Weitzman, CL*; Rostama, B; Belden, L; May, M; Hawley, DM; Virginia Tech, University of New England; *clweitzman@vt.edu*
Protective effects of intact ocular microbiomes in house finches are unrepeatable and not dependent on pathogen dose
The commensal microbes inhabiting a host can interact with invading pathogens and host physiology in ways that alter pathogen growth and disease manifestation. A prior study in house finches (*Haemorhous mexicanus*) found that intact ocular microbiomes were protective against conjunctival infection and disease caused by *Mycoplasma gallisepticum* (MG). Here, we experimentally examined whether protective effects of the resident ocular microbiome vary with the dose of invading pathogen. We hypothesized that commensal protection would be strongest at low MG inoculation doses because the resident microbiome would be less overwhelmed by invading pathogen. Our five MG dose treatments were fully factorial with an antibiotics treatment to perturb and knock down resident microbes just prior to MG inoculation. Our pathology and pathogen load results were inconsistent with those from prior work that found protective effects of the ocular microbiome against MG inoculation. Unexpectedly, we found a trend toward lower pathology in birds with antibiotic-perturbed resident microbiomes, regardless of invading pathogen dose. Amplicon sequencing data indicated that birds began this study with resident ocular microbiomes distinct from those previously reported in our system. Here, the antibiotics may have knocked down resident ocular community members that facilitate rather than protect against MG, leading to a reduction and even a potential reversal in the microbiome's protective capacity. The lack of repeatability of protective effects of the ocular microbiome in house finches reveals the sometimes-limited

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generalizability of ecological results and the likely context dependency in many symbiotic interactions.

39-2 Welc, M*; Wolak, ME; Auburn University; *mzw0091@auburn.edu*
Ecomorphological variation in shell shape of stripe-necked musk turtles (Sternotherus peltifer)
Recent studies on Emydid turtles demonstrate a relationship between shell shape and environmental variation. Turtles in fast-flowing riverine habitats have repeatedly been shown to have flatter shells than those from habitats with little or no water flow, such as ponds or slow-moving rivers. These results are consistent with body shape patterns observed in fishes and other aquatic organisms and hypothesized to be a consequence of local adaptation. Missing are studies with turtles that explicitly address this adaptive hypothesis, especially given the distinguishing characteristic of the turtle shell in that it does not function in locomotion, is a rigid structure, and may represent additional reproductive constraints for flatter turtles. The stripe-necked musk turtle (*Sternotherus peltifer*) inhabits a wide variety of stream habitats throughout its range in the Southeastern United States. Despite its varied habitats, the pattern of shell shape variation has not yet been documented in this or any other bottom-walking turtle species. We used 3D geometric morphometrics to assess shell shape variation in *S. peltifer* from the Cahaba River drainage of central Alabama. The Cahaba drainage is bisected by a fall line, where swift Appalachian streams shift to the slower rivers of the coastal plain. We found an ecomorphological pattern consistent with previous studies on other turtle species. In light of this pattern, we examined clutch size data to determine whether there is a trade-off between shell shape and reproductive output, which would suggest that flatter shells are a local adaptation to fast-flowing environments.

33-6 Weldon, JK*; Rivera, HE; Davies, SW; Boston University; *jweldon@college.harvard.edu*
Effects of divergent temperature stress on microbial communities in Oculina arbuscula

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Increasingly extreme water temperatures caused by climate change continue to have devastating impacts on coral reefs. Corals under thermal stress will bleach, a process in which they lose their photosynthetic symbionts and become vulnerable to disease and mortality. In addition to their symbionts, corals host a diverse bacterial microbiome, which has been previously shown to influence their thermal stress response, pathogen resistance, biogeochemical cycling, and other metabolic processes that allow corals to live in oligotrophic waters. However, how the microbiome interacts with the host when algal symbionts are absent remains unclear. Here, we took advantage of the facultatively symbiotic coral, *Oculina arbuscula* to explore how microbial communities respond to thermal stress in naturally symbiotic and aposymbiotic colonies. Using 16S ribosomal DNA metabarcoding, we compared microbial community dynamics of coral fragments exposed to cold stress (decreasing from 18°C to 6°C) and heat stress (increasing from 18°C to 32°C) over 15 days, relative to controls maintained at 18°C. We found that heat stress elicits a stronger shift in overall microbiome diversity in both symbiotic states, but these effects are divergent. Aposymbiotic colonies showed increased community diversity under heat stress, whereas symbiotic colonies showed a decline, associated with a pronounced increase in the prevalence of Burkholderiaceae. Cold stress led to a decrease of Burkholderiaceae in aposymbiotic colonies and an increase in a variety of other bacterial taxa. While analyses are ongoing, these results will further our understanding of bacterial influences on coral responses to temperatures by disentangling symbiont-coral-bacterial (symbiotic colonies) and coral-bacterial (aposymbiotic colonies) interactions under divergent temperature treatments.

17-6 Weller, HI*; Schwartz, ST; Karan, E; Lord, NP; Brown University, Providence, University of California, Los Angeles, Louisiana State University, Baton Rouge; *hannahiweller@gmail.com*

Recolorize: a flexible R package for color classification

Color and pattern are some of the most conspicuous signals in biology, whether they are naturally present or introduced (*e.g.*, by staining); often, these are the first-noticed and best-documented traits of organisms. An increasing number of methods attempt to quantify some aspect of these signals, typically focusing on a

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particular question, such as sensory ecology (how other organisms view a signal), comparative biology (how the signal has evolved), or anatomy. The first step in most of these methods is to cluster an image into a small number of color classes. This step has proven to be a surprising bottleneck, partly because the problem is not generalizable—image noise in one context could be relevant signal in another. A green-blue gradient might indicate inconsistent lighting on a lizard, while the same gradient on a beetle indicates biologically important iridescence. A common solution to this problem is k-means clustering, which has three major issues: it produces inconsistent results, requires a user-specified number of clusters, and often loses minor elements while over-clustering large ones. More robust alternatives (*e.g.*, micaToolbox) are tailored for sensory biology and require additional information which may not be available. To address this bottleneck, we created recolorize, an R package which provides automatic and manual tools for color classification in images or image sets. Options include hierarchical clustering, layer merging and cleaning, and color fit optimization, along with export tools for popular color analysis packages. We illustrate the use of this package in three contexts: spectral analysis of jewel beetles with pavo, comparative analysis of bird plumage with patternize, and quantification of alizarin-stained bone.

40-3 West, J J*; Evans, K M; Rice University; *jojowest09@gmail.com*
Tied to the tide: developmental differences in sculpin species
The intertidal habitat is a thunderdome that pushes its inhabitants to their physiological limits. Within this rapidly changing microcosm, organisms must navigate intense biotic (e.g. predation threat) and abiotic (e.g. hypoxia, desiccation) stressors to forage and reproduce. Among the most successful dwellers of this naturally exigent environment are members of the Sculpin superfamily, *Cottoidea*. Sculpins are a widely diverse group; some species spend their entire life cycles perpetually navigating intertidal areas, while other species spend the juvenile stages of their lives in these habitats and migrate to subtidal habitats as they mature. Thus, species are adapted to either consistent overexertion or temporary strain, respectively. These marked differences in the natural history of such closely related species

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have the potential to exert differential selective pressures across the body of these organisms and result in different developmental trajectories. In this study we use three-dimensional geometric morphometrics to compare the allometric scaling of urohyal shape in two species of sculpin (*Oligocottus maculosus* and *Myoxocephalus polyacanthocephalus*). The urohyal, an ossified structure known to play a role in fish respiration, is an ideal measuring tool for the pressure exerted on the respiratory system of sculpins in any environment. We predict that *M. polyacanthocephalus* will exhibit larger slopes than *O. maculosus* due to the former's adult migration into subtidal habitats and subsequent distancing from the constraints that come with colonizing intertidal environments.

1-1 Westby, KM*; Medley, KA; Tyson Research Center, Washington University in Saint Louis; *katiewestby206@gmail.com*

Cold nights, city lights: Artificial light at night reduces photoperiodically induced diapause in urban and rural populations of Aedes albopictus

As the planet becomes increasingly urbanized, it is imperative that we understand the ecological and evolutionary consequences of urbanization on species. One common attribute of urbanization that differs from rural areas is the prevalence of artificial light at night (ALAN). For many species, light is one of the most important and reliable environmental cues, largely governing the timing of daily and seasonal activity patterns. Recently, it has been shown that ALAN can alter behavioral, phenological, and physiological traits in diverse taxa. For temperate insects, the ability to enter diapause is an essential trait for winter survival and is initiated by declining daylight hours in the fall. Diapause is under strong selection pressure in the mosquito, *Aedes albopictus*; local adaptation and rapid evolution has been observed along a latitudinal cline. It is unknown how ALAN affects this photosensitive trait or if local adaptation has occurred along an urbanization gradient. Using a common garden experiment, we experimentally demonstrated that ALAN reduces diapause incidence in this species by as much as 40%. There was no difference, however, between urban and rural demes. We also calculated diapause incidence from wild demes in urban areas to determine if wild populations exhibited lower than predicted incidence compared to

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estimates from total nocturnal darkness. In early fall, lower than predicted diapause incidence was recorded but all demes reached nearly 100% diapause before terminating egg laying. It is possible that nocturnal resting behavior in vegetation limits the amount of ALAN exposure this species experiences potentially limiting local adaptation.

99-3 Westerman , EL*; Agcaoili, GA; Ernst, DA; University of Arkansas, Fayetteville ; *ewesterm@uark.edu*

Sexually dimorphic gene expression associated with sexually dimorphic learning in Bicyclus anynana butterflies

Sexually dimorphic behavior is pervasive across animal taxa. Males and females may exhibit different mate selection strategies, parental care behavior, foraging strategies, dispersal, and territorial displays. Though widespread across species and context, the genetic underpinnings of many types of sexually dimorphic behavior are poorly understood. This is partially because males and females carry much of the same genetic material, thus sex specific behavior is unlikely to be allele dependent, except for the rare behaviors that are primarily associated with genes of large effect on sex chromosomes. Here we investigate gene expression patterns associated with a sexually dimorphic social behavior, imprinting-like learning, in the butterfly *Bicyclus anynana*. In this species, both males and females learn, but they learn preferences for different traits, exhibit different learning biases, and are likely using different signals as salient, unconditioned cues. To identify gene sets that may be associated with this sexually dimorphic behavior, we examined the gene expression profiles of brains and eyes of male and female butterflies as they learned from a social experience. As a control, we compared the same tissues of naïve males and females. We found small sets of genes with sex-biased differential expression in the brains and eyes of trained individuals, including genes associated with circadian rhythms and neural processing, as well as some genes with sex-biased differential expression across social contexts. The genes found to have sex-biased differential expression during training provide an initial set of candidate genes for further investigation of previously observed sex biases in social learning.

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45-11 Whelan, S*; Hatch, SA; Elliott, KH; McGill University, Sainte-Anne-de-Bellevue, QC, Institute for Seabird Research and Conservation, Anchorage, AK; *shannon.whelan2@mail.mcgill.ca*

Effects of food supplementation on blood metabolites in pre-breeding seabirds

The capacity for quick and easy assessment of an animal's physiological condition has broad applications for fundamental and applied field ecologists. Many point of care devices—such as personal glucose metres readily available at pharmacies—have been validated to measure metabolites in non-human animals, and use in field studies is increasing. With this boom in interest, field experiments are critical for understanding the mechanisms driving individual variation in circulating metabolites in wild, free-living populations. We used point of care devices and a food supplementation experiment on pre-breeding black-legged kittiwakes (*Rissa tridactyla*) to examine the effects of food availability, sex, and date on four blood metabolites: glucose, ketones, cholesterol, and triglycerides. Food supplementation altered blood metabolite concentrations. These differences were more pronounced in pre-breeding females than males, possibly due to differences in energetic demands leading up to egg-laying. However, the most notable changes were shifts in blood metabolite concentrations as the pre-breeding season progressed; glucose, ketones, and triglycerides increased over time, while cholesterol decreased over time. These results indicate that regulation of metabolite concentrations could be a mechanism for maintaining energy balance under different diets. We also offer recommendations for using point of care devices in field settings, and discuss implications for conservation physiology.

85-5 Whelan, NV; United States Fish and Wildlife Service & Auburn University; *nathan_whelan@fws.gov*

Is phenotypic plasticity a common driver of shell shape variation in freshwater gastropods?

Gastropod shells display a breathtaking degree of morphological diversity. Even with increased reliance on molecular data for modern taxonomic and conservation research, shells still form the

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basis of most gastropod taxonomy. However, intraspecific variation in shell morphology is common, and poor understanding of intra- vs interspecific variation complicates taxonomy and conservation of many gastropod groups. Nevertheless, intraspecific conchological variation is often attributed to phenotypic plasticity (i.e., a single genotype giving rise to multiple phenotypes). This is particularly true for freshwater snails. Here, I review the evidence of phenotypic plasticity as a causal mechanism of conchological variation across all freshwater snails. Phenotypic plasticity has been well documented in some Panpulmonata lineages (e.g., Radix and Helisoma), but experimental evidence on causes of intraspecific morphological variation is lacking for the majority of freshwater gastropod lineages. Furthermore, phenotypic plasticity, when present, often has a small affect on shell shape. This should not be taken to mean that phenotypic plasticity is not selectively advantageous, but phenotypic plasticity rarely, if ever, causes the presence or absence of discrete shell features like spikes or shell ribs (i.e., plicae or carinae). Broadly, intraspecific shell shape variation in freshwater snails has been speculated to be caused by phenotypic plasticity more often than experimentally demonstrated. I argue that phenotypic plasticity should not be a null hypothesis to explain shell shape variation in freshwater snails. More common garden experimental studies are needed to understand if, and what, environmental cues influence shell shape.

73-7 Whitacre, TD*; Goldsmith, HL; Hubicki, CM; Daley, MA; University of California Irvine, Royal Veterinary College, Florida State University; *twhitacr@uci.edu*

Turning in treacherous terrain: Slip and fall risk and locomotion priority in guinea fowl

Locomotion in the real world is rife with trade-offs between task-level demands such as speed, economy, stability, and injury avoidance. Here, we investigate locomotor dynamics in helmeted guinea fowl (Numida meleagris, n=7) on four runways: straight and 90-degree turns, each with high- and low-friction surfaces. We expected turns to shift priority towards force regulation, and slippery terrain to shift priority towards intrinsically stable gaits while limiting the horizontal forces to avoid slips and

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falls. Strategies to achieve this include slower speed, shorter steps, and shallower turn angles. Counter to predictions, slippery substrates did not induce a large shift in turn strategy. Guinea fowl opted for a speed-mediated turning behavior on both substrates, slowing down on turns compared to straight runs, slowing only slightly more in slippery turns compared to control terrain. In slippery turns, speed centered around the walk-to-run transition speed, corresponding to grounded running. After accounting for speed effects, duty factor increased and peak force decreased significantly in turns vs straight runs, suggesting a shift in priority towards stability and force regulation. In slippery turns, birds maintained a more upright posture with increased body height and sagittal leg angle - indicating postural shifts as a strategy for turning in slippery terrain. Despite changes in strategy, guinea fowl slipped in 36% and fell in 17% of trials on slippery turns. Taken together, we posit that slip and fall avoidance may not always be a critical priority for guinea fowl. In ongoing work, we are developing cluster analysis based on ground reaction force features to identify steps with slips and falls, and a model in DeepLabCut to track limb kinematics.

70-4 White, CF*; Lauder, GV; Harvard University, Cambridge Massachusetts; *connor_white@fas.harvard.edu*

Fish locomotion: reconstructing fish midline kinematics from multiple inertial measurement units

Animal-borne data loggers (ADL) recording triaxial acceleration, angular momentum and magnetic strength have been increasingly used over the past 20 years to study the movements of animals. ADLs have allowed researchers to estimate field metabolic rates and kinematic measurements like tail beat frequency and have increased our knowledge of the movement of animals in the wild. However, these tools only provide insight into an animal's movement via a single location on the body. This limits ADLs use for whole body kinematic studies. Our aim was to develop a datalogger from opensource, off-the-shelf components to measure movements at multiple points along an animal, and thus allow for 3D reconstruction of midline kinematics during unrestrained swimming. This new datalogger is designed around a microcontroller (feather adalogger) to record measurements to an SD card from multiple MPU9250 inertial

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measurement units (IMU) placed along the midline of a fish. The readings from each sensor can be fused together to provide a 3D orientation of each location on the body. We have tested this data logger in a computer-controlled flapper in a laboratory flow tank to generate known undulatory kinematics while simultaneously recording high speed video to provide ground truth measurements of body motion. In controlled lab settings, the data logger was able to accurately reflect the timing, direction, and magnitude of movement of multiple locations along the body. This new tag has the potential to allow for whole body 3D kinematic measurements from fish in the field, and a better understanding of the diversity of fish locomotor behaviors.

41-2 White, BJ*; Jackson, BE; Longwood University; *jacksonbe3@longwood.edu*

Coconuts not included: Merging art with real data to animate bird flight

Art as a tool for scientific communication has proven instrumental in the form of both public outreach and data visualization. To disseminate research to wider audience, illustration and animation with clear visual and auditory cues, but that accurately follows raw data, should be prioritized. Here, a 3D model of an American cliff swallow (*Petrochelidon pyyrhonota*) created in Autodesk Maya is rigged to be animated procedurally by following a series of coordinates from video-based 3D reconstruction. The model itself was created to not only match the manually digitized external landmarks in the raw data, but also to simulate the movements of underlying wing anatomy during flight. In order to animate portions of the wing not represented by data points, a variety of different techniques were used, chief among these being inverse kinematics (IK) and set driven keys. IK joints were primarily employed for the undigitized elbow of the wing to provide a reasonable range of flexion and extension during flight. Once the bones of the wing were articulating properly, the tissue and feather meshes were bound to the same rig as the skeleton, allowing all layers of the model to move together simultaneously. The expansion and contraction of the feather groupings were then handled using set driven keys, with two border feathers serving as deformation guides for each group. Ultimately, this rig has the potential to be used

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repeatedly with different data points, allowing for the streamlined creation of data-driven animation for future communication of avian flight dynamics.

1-7 White, JM; National Park Service, Natural Sounds and Night Skies Division, Fort Collins, CO; *Jeremy_M_White@nps.gov*

Measuring light pollution and its impact across the National Park Service

Anthropogenic light at night alters natural ecosystem function by disrupting the natural rhythms of day and night, the driving force behind many biological functions. While the sources of light pollution stem from the built environment, the scattering of anthropogenic light in the atmosphere can be detected hundreds of kilometers from its source. The spatial extent of this scattering, called skyglow, can significantly degrade the photic environment in otherwise pristine or protected natural places such as national parks. The 1916 Organic Act created the National Park Service (NPS) with a mandate to preserve the resources of national parks for future generations. The NPS considers the natural photic environment an integral natural, cultural, historical resource, thus is committed to its protection. To understand the impact of anthropogenic light on park ecosystems and visitor use, the NPS has developed camera systems to precisely measure its intensity and spatial extent from both direct and indirect sources, and to quantify its impact on the natural environment. Twenty years of measurements in over 130 park units has revealed a wide range of exposure to light pollution, from pristine conditions to severely degraded. The sources of light pollution detected in parks are predominantly from sky glow generated by towns and cities, some as far as 200 kilometers away. Here I present techniques used by the NPS to measure the photic environment, measurement results, examples of ecological impacts, and steps taken to preserve this critical resource.

100-1 White, KJ*; Pradhan, DS; Idaho State University; *vanlkatr@isu.edu*

Status resolution: Behavioral differences across two social contexts in bluebanded gobies

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Conspecific aggressive encounters are highly dynamic, involve a spectrum of behavioral traits, and are largely based on reciprocated interactions between or among individuals. Higher circulating androgens in the winner are a hallmark of male-male competition. While female-female competition is not widely studied, in some species, estradiol (E_2), has a rapid effect on aggression in both males and females. Bluebanded gobies, *Lythrypnus dalli* are bidirectionally hermaphroditic fish that live in linear hierarchies with a nesting male and many subordinate females. Disruption of hierarchy via male removal (MR) or male addition (MA) leads to social instability. This study compares the rapid changes during status resolution and systemic E_2 within the hierarchy, between MR and MA groups. In MR groups, the alpha female had significantly higher winning encounters with the beta female and spent significantly more time in the nest. Thus, status between females was resolved through an increase in agonistic efficiency and territory acquisition. In MA groups, there was no significant difference in agonistic behavior between males, but the intruder male spent significantly more time in the nest. Interestingly, male-male interaction involved physical contact inside the nest, including bites, shoves, and lateral displays, that was absent in MR groups. Thus, between males, status was resolved through an acquisition of territory that included a greater intensity of aggression compared to females. Systemic E_2 did not change during status resolution in MR or MA groups. This could be explained by behavior being regulated at a local level in the brain, which is independent of systemic changes. Overall, individuals from the two social contexts differed in their behavioral approach to status resolution.

49-12 Whitehead, N*; Kelly, SA; Demes, JS; Garland Jr., T; University of California, Riverside, Ohio Wesleyan University; *nwhit019@ucr.edu*

Locomotor play behavior in selectively bred high runner mice

Mammals exhibit social play, play fighting, and locomotor play. Locomotor play is defined as vigorous and seemingly purposeless behavior observed in young animals. Play can have negative consequences, such as taking time away from foraging, increasing exposure to predators, and causing injuries. One hypothesized

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benefit of locomotor play is facilitation of neural and muscular development in young individuals with effects that may persist into adulthood. Thus, animals from populations that have an evolutionary history involving natural or sexual selection for high levels of physical activity as adults might have evolved increased play behavior as juveniles as one mechanism that increases adult locomotor abilities. We tested whether elevated locomotor play has evolved as a correlated response in the context of artificial selection for increased voluntary exercise. We studied 4 replicate lines of mice that have been selectively bred for voluntary wheel-running behavior (High Runner or HR) and four non-selected Control (C) lines. Mice were sampled from generations 20 (2-7 days after weaning at 21 days of age), 67 (same), and 93 (15 days of age). Cages that included several individuals were the unit of observation (during the beginning of the scotophase, under red light). We recorded two forms of previously defined locomotor-play behavior: (1) very rapid, horizontally directed jerk-run sequences and (2) rapid 'bouncing' in a vertical direction. Preliminary statistical analyses indicate that HR mice may indeed have evolved increased levels of juvenile locomotor play. Supported in part by NSF grant DEB-1655362 to TG.

S4-9 Whitenack, LB*; French, LB; Hersh, BM; Nelson, MK; Thu, YM; Allegheny College; *lwhitena@allegheny.edu*

FSBio 201: A CURE-based course that scaffolds research and scientific communication

Course-based undergraduate research experiences are a high-impact practice with a number of positive outcomes, including developing scientific reasoning skills, increasing levels of student persistence in the sciences, and making scientific research more inclusive. At Allegheny College, students are introduced to biological research in FSBio 201, which plays two important and distinct roles in the curriculum. First, it serves as a pivot point within the curricular scaffolding provided by the college First-Year/Sophomore (FS) seminar program, wherein students shift from an emphasis on more general oral and written communication towards an introduction to speaking and writing within particular disciplines as they move toward their required senior project. Second, FSBio serves as the first biology laboratory course for majors and

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students in related programs. Students rotate among two or three instructors during the semester, completing experiments of their own design in different biology subdivisions, including molecular biology, genetics, microbiology, physiology, biomechanics, behavior, and ecology. Students also learn data analysis skills and how to find and read scientific literature critically. At the end of each module, students present their findings orally and write a paper in IMRAD format. Assessments indicate that students make strong learning gains in research and communication skills and that the course has a positive impact on their interest in science. The emphasis on experimental design and scientific communication, rather than specific techniques, also makes the course highly adaptable for either in-person or remote delivery. When virtual delivery was required in Spring 2020, students were introduced to epidemiological research, making use of publicly-available databases.

54-5 Whitlow, KR*; Ross, CF; Gidmark, NJ; Westneat, MW; University of Chicago, Knox College; *kwhitlow@uchicago.edu*

Cranial kinesis in actinopterygian suction feeding: mechanical correlates of prey motion in Polypterus bichir

Many fishes rapidly expand the oral cavity to draw prey into the mouth via suction feeding. Teleosts achieve suction using substantial cranial kinesis, including neurocranial elevation, suspensorial and opercular flaring, jaw and hyoid depression, and premaxillary protrusion. Polypterids share some of this mobility but lack protrusible jaws and a dual mechanism for mandibular depression, potentially reducing degrees of freedom in the feeding system. Despite this restricted mobility, *Polypterus* remain effective suction feeders, making them a useful system for understanding the basic components of suction feeding in actinopterygians. The goal of this study was to identify specific bone motions linked with suction feeding performance in *Polypterus bichir*. We predicted that ventral translation of the jaw and hyoid bar and lateral translation of the suspensorium would be highly correlated with prey velocity and acceleration. We quantified motions using XROMM and tested cross-correlations between prey velocity and dorso-ventral, medio-lateral, and antero-posterior translations of 5 skeletal elements (neurocranium, suspensorium,

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mandible, ceratohyal, and operculum) in 14 trials. Retraction and depression of the anterior ceratohyal and lateral flaring of the posterior ceratohyal are correlated with prey velocity ($r > 0.69$; $p < 0.05$, respectively); suspensorial flaring is not correlated with prey velocity. In these strikes *P. bichir* generated suction primarily through extreme motions of the ceratohyal, rather than through protrusion of the jaws or mobility of the palate. This suggests that while other kinesis mechanisms may enhance suction performance, ceratohyal mobility drives actinopterygian suction feeding. NSF DEB 1541547, MRI 1338036, SR01DE023831-04S1, MRI1626552.

99-1 Wice, EW*; Saltz, JB; Rice University, Department of BioSciences, Houston, TX; *eric.wesley.wice@gmail.com*

Indirect genetic effects on social network structure: An extended-extended phenotype

The position an individual holds in a social network is dependent on both the direct and indirect social interactions an individual engages in. When an individual's genotype impacts its own network position, as well as the network positions of group conspecifics, both direct and indirect genetic effects can influence network position. Because social network position is dependent on the actions and interactions of conspecifics, it is likely that the genotypic composition of individuals within a social group impacts individuals' network positions. However, we know very little about whether social network positions have a genetic basis, and even less about how the genotypic makeup of a social group impacts network positions and structure. With ample evidence indicating network positions influence various fitness metrics, studying how direct and indirect genetic factors shape network positions is crucial for understanding how the social environment individuals experience responds to selection and evolves. Using replicate genotypes of *Drosophila melanogaster* flies, inbred from a natural population, we created replicate social groups that varied in their genotypic makeup. Social groups were videoed, and networks were generated using motion-tracking software. We found that an individual's genotype is a strong predictor of its network position, with broad-sense heritability estimates ranging from 2.4 – 16.6%. Preliminary results indicate an individual's network

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position is also dictated by the genotypic makeup of its social group, and the effect of an individual's genotype on its own network position may depend on the genotypes of its social group partners as well.

42-4 Wilcoxen, TE*; Albin, M; Giannuzzi, K; Koch, N; Lukens, E; Phillips, A; Spence, J; Millikin
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An indomitable invader? Physiological tolerance across diverse early-life stressors in an invasive treefrog

One of the hallmarks of successful biological invasions is ecological release from the factors that regulate an organism's population in their native range. However, species that possess traits that allow them to tolerate a broad range of novel stressors also tend to be successful invaders. One of the most successful invasive amphibian species in the Florida peninsula is the Cuban Treefrog (*Osteopilus septentrionalis*). While much of its success in the invasive range can be attributed to competitive advantage and direct predation upon competitors, our research team and others have demonstrated that tolerance to a diverse set of stressors is likely a major contributor to Cuban Treefrog success in Florida. While some of these studies have focused on adult treefrog tolerance, our work has primarily focused on tadpole responses to stressors. Through a series of experiments, we have found Cuban Treefrog tadpoles to be resistant, or generally non-responsive, to tail damage, elevated salinity, water acidification, temperatures below those experienced in their current invasive range, environmentally-relevant levels of cypermethrin, and direct elevation of corticosterone levels. Taken together, these experiments reveal Cuban Treefrog tolerance to a broad range of environmental conditions that are known stressors with deleterious effects in other amphibian species.

98-1 Wilken, AT*; Sellers, KC; Cost, IN; Middleton, KM; Witmer, LM; Holliday, CM; University of Chicago, University of Missouri, Albright College, Ohio University; *atwilken@uchicago.edu*

Bird brains, jaw muscles, and the origin of avian cranial kinesis

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The vertebrate skull operates under competing demands to facilitate a functioning feeding apparatus while housing and protecting sensory organs. These competing demands are both mechanical and spatial in nature. Cranial form and function therefore represents trade-offs between these demands. The evolution of the avian cranium involved dramatic increases in brain size as well as biomechanical shifts in the feeding apparatus. Most notably, the evolution of the avian skull represents the transition from the akinetic skulls of early dinosaurs to the highly kinetic skulls observed in modern birds. Using an integrated approach of morphometrics, muscle modeling, and free body force analysis, we quantified the muscle orientation change across the theropod-bird transition and its biomechanical effects on the moments and reaction forces of the joints necessary for cranial kinesis. We demonstrate that wider braincases arranged jaw muscles into more rostrocaudal positions in birds, creating net moments about cranial joints suggestive of mobility. Joint reaction forces shift to a more rostrocaudal orientation in birds, with highly kinetic birds having relatively low reaction forces from the otic joint. These data complement and expand upon our current understanding of the evolution of cranial kinesis in tetrapods and the role of intracranial joints in vertebrate feeding.

BSP-1-2 Williams, BL*; Gray, SM; Pintor, LM; The Ohio State University; *williams.4234@osu.edu*

The effect of hypoxia and turbidity on male courtship behavior

Mate choice is crucial to reproductive success because potential mates vary widely in the quality of resources or genetic material provided to their offspring. Hypoxia (low oxygen) and turbidity (suspended particulate matter) are two environmental conditions that can strongly affect reproductive behavior because hypoxia favors the reduction of energetically costly activities and turbidity disrupts visual communication. *Pseudocrenilabrus multicolor*, an African cichlid, is highly abundant in both swamps and rivers, but these two environments pose two very different contexts in which to assess potential mates, so studying their reproductive behavior can provide insights into how plastic changes in behavior can facilitate persistence in environments impacted by humans. To determine whether rearing treatment (high/low DO,

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high/low turbidity) affects courtship behavior, we conducted mate choice trials (n=80) where we measured the time spent (s) by males in courtship behaviors. Preliminary results (n=39 trials; Two-way ANOVAs and Tukey's tests) indicate that population did not affect the time spent in male courtship behaviors, but rearing treatment does impact the time spent by males in lateral displays ($F_{3,73}$ =3.526, p=0.019) and charging ($F_{3,73}$=11.214, $p < 0.001$), but not quivers which were rarely observed ($F_{3,74}$=1.595, p=0.198). Unexpectedly, hypoxic males spent more time charging than normoxic males and males from the hypoxic-clear treatment spent more time displaying than males from the other three treatments. Because changes in reproductive behaviors can lead to changes at the population or community level, further study on the effect of these challenging environments on reproductive behavior is warranted.

BSP-5-2 Williams, SG*; Grindstaff, JL; Oklahoma State University; *sierra.g.williams@okstate.edu*

Early viral immune challenge alters adult behavioral phenotype in the zebra finch (Taeniopygia guttata)

Early viral immune challenge (EVIC) may alter adult behavioral phenotype of challenged individuals. Activation of an antiviral response via innate immune pathways initiate a cascade of potent inflammatory cytokines. Neonates have a limited ability to synthesize antibodies, thus innate mechanisms, like inflammation are crucial for viral clearance. This inflammatory response may program adult behaviors, impacting overall fitness. Our objective was to elucidate the interaction between EVIC and adult learning proficiency and neophobia in zebra finches (*Taeniopygia guttata*). We challenged nestling zebra finches to a synthetic dsRNA virus, Polyinosinic-polycytidylic acid (Poly I:C). At 6 months post-hatch, birds were tested for neophobia and learning proficiency. Neophobia scores were determined by behavioral responses to 2 novel objects. Learning proficiency was determined by success in a novel foraging trial. Birds that had been challenged with Poly I:C had a lower overall probability of trial success, and the probability of trial success decreased as pre-trial weight increased. However, compared to control birds, challenged birds with larger pre-trial weights had a higher probability of trial success. I will also present my findings on the impact of EVIC on neophobia. As behavior and

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immunity often covary, and behavior can subsequently affect an individuals' disease risk, this research has the potential to inform models of disease transmission dynamics as birds play a key role as viral hosts/amplifiers.

91-1 Williams, TM*; Antoine, AO; Martine, CT; Bucknell University; *tmw018@bucknell.edu*

Using population genomics to understand the influence of biogeographic barriers on Templetonia hookeri (Fabaceae), an endemic legume of the Australian monsoon tropics

To understand species distributions, more knowledge is needed to elucidate the roles of how genomic variation and the impacts of biogeographic barriers shape present occurrences. The biodiversity and climatic histories of the Australian Monsoon Tropics (AMT) provides a unique system for investigating evolutionary processes. The AMT is a topographically and climatically diverse biome where well-known biogeographic barriers have been proposed as drivers of distribution patterns leading to closely-related taxa that are geographically isolated and morphologically distinct. The barriers are thought to have facilitated the large number of endemic angiosperms. However, the opposite pattern has been observed in *Templetonia hookeri*. It is broadly distributed across several barriers and appears to be morphologically stable across its range. Population genomic methods were used to analyze the genetic diversity and population structure of *T. hookeri*, and assess barrier impacts. We used a genotyping-by-sequencing (GBS) approach to assess the status of 13 populations. Results show that populations are highly isolated, are structured by geography, and inbreeding is prevalent. Genetic clustering methods also corresponded with known barriers. The significant lack of genetic diversity within populations, coupled with the support for highly structured populations, provides evidence that although populations may look similar, they are genetically distinct. This work is part of a broader project highlighting the role of AMT sandstone escarpments as habitat refugia for angiosperms during the Last Glacial Maximum, the first attempt to test for the effects of multiple biogeographic barriers across angiosperms in the AMT.

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Time scales of mixing in an imperforate scleractinian coelenteron

Coelentera are the largest components by volume in the gastrovascular system connecting polyps in a scleractinian colony. Thus to understand colony connectivity which is predicted to affect corals' response to environmental change, we must first describe the dynamics inside these gastric cavities of individual polyps. We determined key time scales of mixing in coelentera by using microelectrodes to measure oxygen concentration after a light-to-dark transition in three polyps each of three colonies of *Montastraea cavernosa* in the laboratory. The gastrovascular system was modeled as an electrical network where voltage represents oxygen concentration, current represents oxygen flux, capacitors represent volume compartments, and resistors represent impedance to oxygen flux. The time constant of mixing, defined as the time needed for the system to disperse 63.2% of the fluid in the coelenteron, was determined from the oxygen dynamics in the coelenteron as modeled by a resistor-capacitor network. Time constants were on the order of three minutes and oxygen dynamics were well fit by the model prediction. However, as polyps depleted oxygen, we observed small magnitude (~ 0.1 ppm), high-frequency fluctuations in oxygen concentration. A power spectral density analysis identified two time scales of high-frequency mixing in the coelenteron. The greatest variance occurred at a period of 48.3 ± 2.8 sec, with a secondary peak seen at 35.9 ± 2.3 sec. The microenvironment within polyps of *M. cavernosa* can respond as fast or faster than their external environment can fluctuate, thus scleractinian polyps have the capacity to mediate their response to changing environmental conditions.

S7-11 Wilts, BD; Adolphe Merkle Institute, Fribourg,
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Rainbows in nature: disordered photonic structures tuned by pigments

Controlling light through photonic nanostructures is important for everyday optical components, from spectrometers to data storage and readout. In nature, nanostructured materials produce wavelength-

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dependent colours that are key for visual communication across animals and act as signals for mates or predators alike. The striking appearance of many animals is obtained by a combination of pigments and nanostructured dielectric material on the order of a few hundreds of nanometres. By changing the morphology of these nanostructures or the composition of pigments, incident light can be manipulated in different ways giving rise to the brilliant displays observed in butterflies, beetles, spiders and birds. The expression of pigments in different areas can play important roles in tuning and altering optical properties. Here, I will show the optical properties of different morphologies found in butterflies and beetles that can range from simple thin films and photonic crystals to structures with (correlated) disorder and show which tricks nature employs to achieve all colours of the rainbow.

S11-12 Wirsing, AJ*; Newsome, TM; University of Washington, The University of Sydney; *wirsinga@uw.edu*

Scavenging effects of large canids

Many large predators are also facultative scavengers that may compete with and depredate other species at carcasses. Yet, the ecological impacts of facultative scavenging by large predators, or their "scavenging effects", still receive relatively little attention in comparison to their predation effects. To address this knowledge gap, we comprehensively examine the roles played by and impacts of facultative scavengers, with a focus on large canids: the African wild dog (Lycaon pictus), dhole (Cuon alpinus), dingo (Canis dingo), Ethiopian wolf (C. simensis), gray wolf (C. lupus), maned wolf (Chrysocyon brachyurus), and red wolf (C. rufus). Specifically, we (i) provide a conceptual overview of the community interactions around carrion that can be initiated by facultative scavengers, (ii) review the evidence for scavenging effects of large canids, (iii) discuss external factors that may diminish or enhance the effects of large canids as scavengers, and (iv) identify aspects of this phenomenon that require additional research attention.

S12-12 Wirthlin, M; Carnegie Mellon University, Pittsburgh, PA; *mwirthlin@cmu.edu*

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Manakin neurogenomics reveal the mechanisms underlying the evolution of skilled motor behavior

How are skilled motor behaviors - such as the ability to sing and dance - encoded genetically? A diverse array of circuits and cell types all work in concert to produce behavior, the result of millions of years of evolutionary optimization at the level of the genome. Genetic changes resulting in the evolution of novel behaviors are rarely identified in genes themselves, which are highly conserved across species. Rather, recent work suggests a critical role for the other 98% of the genome, the noncoding regions that orchestrate gene activity. To elucidate the relationship between motor behavior and sequence evolution, we sequenced and extensively analyzed the genomes of 5 manakins (*Pipridae*), an avian family characterized by their extreme sexual dimorphism. Males of various species engage in virtuosic courtship dances, involving leaps, loops, and moonwalks that are as rapid as they are precise. We identified manakin gene regulatory specializations through a comparison of thousands of conserved noncoding elements (CNEs) across dozens of additional avian genomes. A subset of these CNEs was found to be evolutionarily accelerated uniquely in the manakin lineage. These elements are not randomly distributed across the genome, but rather are clustered around genes relevant to manakin behavior, including steroid signaling, motor learning, and brain development. We localized the expression of a subset of these genes to brain areas involved in fast visual tracking, suggesting that the CNEs proximal to these genes may represent regulatory regions associated with the perception of manakins' high-speed courtship displays. In sum, this work provides a template for how we might accelerate discovery into the regulatory genomic mechanisms of behavior through a neuroethological approach to comparative genomics.

72-6 Wiseman, ALA; Bishop, PJ; Demuth, OE; Cuff, AR; Michel, KB; Hutchinson, JR*; Royal Veterinary College, Hatfield, United Kingdom; *jhutchinson@rvc.ac.uk*

Biomechanical modelling of musculoskeletal leverage gives insight into locomotion of Nile crocodiles

Biomechanical modelling approaches which can accurately estimate musculoskeletal functions have offered unique insights into the

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locomotion of extant animals, which in turn can provide the basis for simulating extinct animal movement. We tested whether Nile crocodiles, which use a variety of limb postures during movement, adopt limb orientations that optimise the moment arms or moment-generating capacities of their muscles during different postures ranging from high walks to more sprawling gaits. We followed a rigorous process in which crocodile dissection data (muscles' architectural properties) were collected, three specimens were CT-scanned (for segmental mass/inertial properties and skeletal structure; and contrast staining for muscle visibility), muscle lines of action were generated in Rhinoceros 4.0 and inverse simulations were computed in OpenSim 3.3, with kinematic data from experimental XROMM (biplanar fluoroscopy) and kinetic data informed by single-limb force platforms. Results did not fully support the hypothesis that optimal poses are used during different locomotor behaviours. We infer a biomechanical trade-off between executing different postures, meaning that the hindlimb's leverages are not optimised for any single posture or behaviour. Our model provides 3D estimates of muscle actions in extant crocodiles for comparison with and reciprocal illumination from extinct archosaurs, for reconstructing locomotor evolution.

62-4 Wohlleben, AM*; Steinel, N; Baker, JA; Foster, SA; Clark University, Worcester, MA , UMass Lowell, Lowell, MA; *Awohlleben@clarku.edu*

Replicated evolution in the threespine stickleback (Gasterosteus aculetus) - Schistocephalus solidus host-parasite System

Helminths are frequent parasites of natural fish populations but interactions of helminths with the fish immune system are under-studied. Infection rates often vary substantially among host populations, on local and global scales. In southcentral Alaska, oceanic stickleback populations have colonized freshwater habitats repeatedly and independently in the 12,000 yr since the last glacial maximum, resulting in a freshwater adaptive radiation. Upon colonization of freshwater, oceanic stickleback first encounter *S. solidus*, a trophically transmitted cestode that has a long evolutionary history of parasitizing freshwater stickleback but is not viable in marine environments. Initial work in British Columbia suggests, as expected, that oceanic stickleback exhibit little

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resistance to infection, whereas freshwater populations exhibit lower infection rates under experimental conditions, suggesting evolved resistance. A crucial step in understanding the interaction in such systems is to examine whether stickleback populations exhibit underlying differences in immune expression profiles. To do so, I am looking at immune profiles of different Alaskan freshwater populations as well as one oceanic population as ancestral proxy, which have been raised under controlled conditions.

110-1 Woldt, K*; Sustaita, D; Pratt, RB; California State University, San Marcos, California State University, Bakersfield; *woldt002@cougars.csusm.edu*

Climbing behavior and skeletal anatomy of the salt marsh harvest mouse

The salt marsh harvest mouse, *Reithrodontomys raviventris*, is an endangered specialist, exclusively confined to the marshes of San Francisco. Understanding the morphology and conferred locomotor capabilities of the salt marsh harvest mouse is increasingly important as climate change induces vegetative and sea level fluctuations. The western harvest mouse (*Reithrodontomys megalotis*) also inhabits the San Francisco wetlands as a portion of its expansive range. The ability to climb vegetation rooted in the marsh to avoid tidal surges may be an important factor of *R. raviventris* survival. Conversely, *R. megalotis* likely avoids inundation by travelling upland, away from the bay edge. *R. raviventris* tends to employ its tail as a prehensile appendage during climbs, a behavior akin to arboreal/scansorial species. Long, prehensile tails are composed of a higher number of cranial-caudally shorter vertebrae, permitting flexibility and increasing torsion tolerance. Prehensile tail muscularization may lead to vertebral process lengthening to facilitate muscle attachment. Higher phalangeal indices are also associated with increasing arboreality in mammals. Relatively long digits allow climbers to wrap feet fully around the substrate, thereby increasing correctional torque abilities. To understand if the climbing activity of *R. raviventris* observed in the marsh is accompanied by skeletal adaptations, I will use micro computed tomography of carcasses to compare its post-cranial skeletal anatomy to that of *R. megalotis*. I predict that *R. raviventris* will exhibit higher

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phalangeal indices, longer vertebral processes, and a higher number of caudal vertebrae than its comparator, indicative of specialization within its dynamic habitat.

70-3 Wolf, Z*; Lauder, GV; Harvard University; *rzanewolf@gmail.com*
Why so many fins? A first look at how Polypterus senengalus use their finlets
Finlets are small fins located on the dorsal and/or ventral midline of a fish, between their dorsal or anal fin and the caudal fin. For the most part, finlets are observed in pelagic, high-performance swimming species, such as scombrids and carangiforms, and finlets appear to have evolved independently in several lineages of teleost fishes. Recent computational work on tuna and mackerel has shown that finlets increase a swimming efficiency and that rows of finlets in series can reduce drag. However, *Polypterus*, in the family Polypteridae, is a member of the most primitive living group of ray-finned fishes, and species may have between seven and twelve finlets that extend along the dorsal body margin. The function of these finlets during locomotion is unknown. In order to investigate finlet function in *Polypterus senegalus*, we (1) investigated their morphology using uCT scans and dissection, and (2) studied finlet movements during both steady and unsteady locomotion using high-speed video. *Polypterus* finlets each have an anterior spine, which allows for their elevation and depression. This contrasts with tuna finlets, which only oscillate laterally and cannot be actively elevated or depressed significantly. We use DeepLabCut to track and measure various kinematic variables of the body and finlets (e.g. swimming behavior and frequency, finlet lateral excursion angle and elevation angle) to determine if finlets provide a hydrodynamic function for *P. senegalus* during steady and unsteady swimming. Preliminary studies suggest finlets appear to be depressed during acceleration but are elevated during slow speed swimming. Likewise, *P. senegalus* finlets increase in dorsal elevation angles and lateral excursion from anterior to posterior along the length of the body, and finlet height and lateral excursion vary among swimming behaviors.

74-4 Wölfer, J*; Michel, J; Aschenbach, T; Nyakatura, JA; Humboldt-

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Universität zu Berlin, Berlin, Germany; *jan.woelfer@gmx.de*
A small squirrel (Tamiops swinhoei) sheds light on the complex biomechanical adaptations to fast arboreal locomotion
Arboreal locomotion is characteristic for many taxa within the mammalian superclade Euarchontoglires, which includes, e.g., primates, and rodents. Early fossils of Euarchontoglires share various morphological similarities with many extant arboreal mammals (small body size, claws on all digits, limited prehensility), suggesting arboreal locomotion to be the ancestral condition of this superclade. The locomotion of extant species is often studied to understand the necessary biomechanical adaptations of early arboreal ancestors. However, studies commonly focus on symmetrical gaits typically used at lower running speeds or when confronted with compliant or very narrow substrates. Fast locomotion exploiting asymmetrical gaits is rarely considered. The small squirrel *Tamiops swinhoei* (Scuiromorpha) is a representative species of this type of locomotion. We analyzed its locomotion at different running speeds while confronting it with different inclinations and substrates (flat runway vs. narrow pole). We simultaneously recorded high-Hz videos and substrate reaction forces during 450 trials. The squirrels almost exclusively used asymmetric gaits. Differences between locomotion on the narrow pole and on the flat runway were interpreted as typical adjustments to arboreal locomotion also found for symmetrical gaits. However, the differences themselves strongly depended on inclination and running speed, hinting at the important role of biomechanical fine-tuning during fast arboreal locomotion. Our findings complement previous studies in developing an understanding of the locomotor behavior of the ancestors of Euarchontoglires.

S8-2 Wolff, JO; Macquarie University, Sydney, Australia; *JONAS.WOLFF@MQ.EDU.AU*
Sticky predator-prey interactions: The ecology of adhesive secretions in arachnids
The coevolution of predators and prey is one of the most important causes of outstanding biomechanical performance. In small animals, gluing is a common and efficient strategy to capture and immobilize fast and strong prey as it may permit direct action without the involvement of muscles. Here, I will present some intriguing and

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poorly known examples of adhesive systems that play a role in arachnid predation. Harvestmen (Opiliones) use small amounts of a viscoelastic secretion to capture springtails. Remarkably, this natural 'pressure sensitive adhesive' may generate a high contact area on the nano-patterned omniphobic cuticular surface of the collembolan. This is achieved by the unique and complex microstructure of the setae that deliver the secretion. The shear-thickening behaviour of the glue effectively permits the generation of a high tensile strength to withstand the strong impacts elicited by the struggling prey. Ground spiders (Gnaphosidae) subdue hazardous prey, such as ants and other spiders, by applying sticky silk coming from modified so-called piriform glands. This silk exhibits a high toughness and is discharged from special enlarged spigots that are actived by elevated hemolymph pressure. Daddy-longleg spiders (Pholcidae) may even produce two different types of piriform gland adhesives, one of which is a rapidly drying secretion used in wrap attacks and defense, and another one being a permanently tacky secretion used to build silken web traps. This is achieved by the addition of organic salts that bind water and to keep the proteinaceous secretion hydrated. These observations are not only important for our understanding of the evolution of functional biomaterials, but may also be promising candidates for biomimetic approaches towards the design of novel sustainable high-performance adhesives.

49-3 Wood, BM*; Le, E; Postupaka, D; Svensson, K; Uhm, C; Pfister, P; Ellerby, DJ; Wellesley College, MA; *bw100@wellesley.edu*

Field observations provide biological context for interpreting laboratory data: The locomotory performance of Bluegill Sunfish (Lepomis macrochirus) as an example

Field observations of animal behavior are essential for guiding the interpretations of laboratory data in order to ensure that they coincide with biological reality. Knowing how an organism behaves in its natural environment is a necessary first step in bridging the gap between experimental data collected in the controlled, artificial environment of the lab and explaining the adaptive significance of measured traits. Field observations also challenge assumptions about behavioral definitions and the apparent discreteness of behaviors measured in the lab. As part of an

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ongoing study in the locomotor performance of Bluegill Sunfish (*Lepomis macrochirus*), we illustrate the role field observations play in contextualizing and expanding interpretations of experimental data and standard assumptions about Bluegill behavior. A comprehensive field study of Lake Waban (Wellesley, MA) and its inhabitants was carried out using underwater cameras, fish finding sonar, and temperature/luminosity loggers to develop a behavioral profile of Bluegill relative to their habitat and interspecific interactions. Although previous experimental work assumed Bluegill adopted locomotor strategies that maximized energy efficiency, field observations demonstrate that swimming performance is driven by a myriad of abiotic and biotic factors. These factors include the need to navigate complex habitats, to flee from predators, to adopt context-specific foraging strategies, to ward off rivals, and to coordinate social interactions. These observations add an extra dimension for understanding why Bluegill adopt particular swimming behaviors and how those behaviors might be adaptively significant at each stage of their life history.

41-6 Woodley, SK; Duquesne University; *woodleys@duq.edu*

Four years of community-engaged learning in a summer undergraduate research program: successes and lessons learned

As the pace of technology and globalization increases, there is increasing concern about the scientific literacy of Americans. A scientifically literate public is necessary for developing a workforce that can understand and solve numerous problems facing the world and for improving the welfare of self and others. Poor science literacy is exacerbated by the general failure of scientists to effectively engage with the public. However, scientists rarely have an opportunity to develop and practice the skills and disposition for meaningful public engagement. To address this training gap, we have incorporated community engagement into our 10 week summer undergraduate research program. Our "scientists-in-training" devoted 1-2 hrs per week to translate their research programs into science activities that they shared with youth attending a day camp in a Pittsburgh neighborhood. Attitudes towards community-engagement were assessed using a retrospective post-test. Here, I will summarize the results of four summers, describing learning gains as well as difficulties and limitations.

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Results indicate that community-engaged learning via sharing science with children is a meaningful addition to a summer undergraduate research program. By giving scientists-in-training opportunities to share science with the non-expert public, we hope they will become better communicators and more receptive to civic engagement in the future. This work was partially funded with grants from the NIH (R25) and the NSF (REU).

65-8 Woodruff, MJ*; Rosvall, KA; Biology, Indiana University, Bloomington; *woodrufm@iu.edu*

Assessing the functional consequences of climate change: tissue-specific responses to heat in a wild bird

As the Earth continues to dramatically warm, experiments on the mechanisms facilitating thermal tolerance can offer important insights into the functional effects of climate change. Previous work, largely studying ectotherms, has established that heat induces various stress responses, including the upregulation of heat shock proteins (HSPs) that counteract cellular damage. However, tissue-level variation in HSP responses remains unclear, leaving uncertainty as to which tissues, and by extension which traits, are more or less buffered from heat. To test the hypothesis that tissues vary in the degree of protection against heat, we experimentally simulated a naturalistic 7-day heat wave inside the nestboxes of wild tree swallows (*Tachycineta bicolor*). Using air-activated warmers, we elevated nest temperatures by at least 2° C, starting when chicks were 6 days old. In heated and control nests, we collected morphological data and measured HSP gene expression in the blood every third day. At the end of the experiment, we collected additional tissues, including the brain, and used qPCR to measure HSP gene expression. We compared tissues to begin exploring which physiological functions may be most affected by heat. We also assessed the degree to which HSP gene expression is correlated with other fitness-related traits, such as mass and wing length. Exploring mechanisms of thermal tolerance in tree swallows is particularly relevant because these birds are currently undergoing a unique southward range shift, breeding in warmer climates, suggesting they may be adapted to heat. More broadly, this experiment informs our understanding of how endotherms cope with the rising temperatures of climate change.

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50-6 Woodruff, GC*; Willis, JH; Phillips, PC; University of Oklahoma and University of Oregon, University of Oregon; *gcwoodruff@ou.edu*

Widespread changes in gene expression accompany body size evolution in nematodes

Body size is a fundamental trait that drives multiple evolutionary and ecological patterns. *Caenorhabditis inopinata* is a fig-associated nematode that is exceptionally large relative to other members of the genus, including the closely related model system *C. elegans*. We previously showed that *C. inopinata* is large primarily due to postembryonic cell size expansion that occurs during the larval-to-adult transition. Here, we describe gene expression patterns in *C. elegans* and *C. inopinata* throughout this developmental period to understand the transcriptional basis of body size change. We performed RNAseq in both species across the L3, L4, and adult stages. Most genes are differentially expressed across all developmental stages, consistent with *C. inopinata*'s divergent ecology and morphology. We also used a model comparison approach to identify orthologs with divergent dynamics across this developmental period between the two species. Notably, among such genes were two transcription factors previously shown in *C. elegans* to be important for body size that are regulated by TGF-β signaling, whose downstream zinc-finger transcription factor SMA-9 also has evidence of lineage-specific selection in *C. inopinata*. *C. elegans*-specific ontology enrichment reveals genes with divergent developmental dynamics tend to be expressed in neurons and regulate behavior; they also include genes important for molting and body morphology. A comparison of such genes with previous *C. elegans* experiments reveals overlap with stress response, developmental timing, and small RNA/chromatin regulation. These results have identified candidate genes that will be further investigated to test their roles in cell size divergence and broaden our understanding of the genetic bases of body size evolution.

70-7 Wu, C*; Howle, LE; Nowacek, DP; Marine Science and Conservation, Duke University, Mechanical Engineering and Materials

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Science, Duke University, Marine Science and Conservation and Electrical and Computer Engineering, Duke University; *chen.yi.wu@duke.edu*

Minimum drag on a three-dimensional North Atlantic right whale model via neutral trim pose

Animals experience hydrodynamic forces (lift, drag, side) and moments (yaw, pitch, roll) as a result of motion in an aqueous medium. Extra momentum imparted into the fluid from lift and side forces as well as yaw, pitch, and roll moments (here, the parasitic loads) results in extra drag on the animal. Animals minimize energy expenditure by streamlining, delaying flow separation, and minimizing excess fluid momentum from parasitic loads. Numerous studies have attempted to evaluate the energetics and swimming performance of aquatic animals. Here, we considered drag to be not only a function of body shape and flow regime but also a function of parasitic loads. We used computation fluid dynamics on a 3-D North Atlantic right whale model to minimize drag by eliminating parasitic loads; thereby eliminating momentum from the wake not caused by drag alone. We found that minimum drag, which corresponds to the elimination of the parasitic loads, can be obtained by adjusting the pose of the animal. Thus, minimum drag occurs at the neutral trim pose. For our specific model, simulations revealed that by changing the angle of attack of the flippers by 4.0315° (relative to the free-stream flow) and pitching the spine downward by 5° while maintaining fluke angle, the drag was lowered by approximately 11% across the speeds tested. This drag reduction was relative to our previous drag study on the same animal model but without body pose adjustments. This finding underscores the need to find the model's neutral trim pose for drag simulations.

33-7 Wuitchik, DM*; Aichelman, HE; Atherton, KF; Kriefall, NG; Tramonte, CA; Davies, SW; Boston University, Boston College; *wuitchik@bu.edu*

Symbiotic state influences transcriptional responses of facultatively symbiotic corals in response to thermal challenges

The symbiosis between coral hosts and algae of the family Symbiodiniaceae is highly sensitive to thermal stress. This tightly interwoven and often obligate symbiotic relationship makes it difficult to uncouple the host's stress response from that of their

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algal symbiont. Facultatively symbiotic corals can exist in symbiotic (brown phenotype) and aposymbiotic (white phenotype) states and offer a unique opportunity to uncouple this symbiotic relationship. Here, we leveraged different symbiotic states to investigate the role of symbiosis in governing the coral host's response to thermal challenges. We conducted a common garden experiment and compared the responses of symbiotic and aposymbiotic fragments of two facultatively symbiotic coral species, *Astrangia poculata* and *Oculina arbuscula* , under both hot and cold thermal challenges. Fragments of each species were exposed to three temperature treatments: i) control (static 18° C), ii) heat stress (18 to 32° C ramp over 15 days), and iii) cold stress (18 to 6° C decrease over 15 days). When temperatures were most divergent, we sampled for gene expression profiling to uncover the molecular signatures of the host's stress response in and out of symbiosis. While gene expression analyses are ongoing, we hypothesize that stress responses in symbiotic corals, at least under heat stress, will be stronger due to symbiotic hosts having to contend with reactive oxygen species produced by algal symbionts. By studying the effects of thermal extremes in a facultatively symbiotic coral and leveraging the power of gene expression profiling, this study will disentangle the role of symbiosis in the generalized stress response, which will transcend our understanding of symbiosis maintenance and bleaching in reef-building corals.

36-6 Wynd, BM*; Uyeda, JC; Virginia Tech, VA; *bmwynd@vt.edu*

Absolute fitness explains evolutionary patterns at the micro and macro levels

Microevolution tells us that genetic variation is high, and selection is strong, meaning evolution acts quickly. This is contrasted by macroevolutionary patterns, where evolutionary stasis occurs repeatedly, and phenotypic change is slow. These two approaches to studying evolution contradict one another, and no model can produce macroevolutionary patterns with microevolutionary parameters. A common approach to this issue has been to attribute macroevolutionary trait change and diversification to speciation alone. Speciation is hypothesized to occur in bursts followed by stasis, invoking ecological opportunity or stabilizing selection as drivers. In contrast, we argue that increasing speciation rates

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through reproductive isolation alone is unlikely to yield adaptive radiation or increased macroevolutionary diversification. Instead, we identify demographic parameters are likely key in driving rates of diversification and trait change. To test this, we performed an approximate Bayesian computation of a discrete island model under two states: static and dynamic adaptive landscapes. We sampled phenotypic variance, heritability, adaptive landscape width, population size, absolute fitness at the adaptive landscape peak, migration rate, and, in the dynamic model, adaptive peak drift, from distributions based on empirical measurements of populations. We simulated 10 million generations across 20 to 101 adaptive peaks Absolute fitness was recovered as the key parameter that explains both adaptive radiation and stasis on macroevolutionary timescales. Ecological opportunity is interpreted here as an increase in absolute fitness across the adaptive landscape, where valleys have fitness > 1 until niches are colonized and valleys return to extinction traps. Absolute fitness controls the pace of trait change and speciation, linking micro and macroevolutionary patterns.

BSP-8-2 Wynne, NE*; Chandrasegaran, K; Vinauger, C; Virginia Polytechnic Institute and State University; *nwynne@vt.edu*

How do mosquitoes escape visual threats?

Mosquitoes' survival is largely dependent on them surviving interactions with their hosts. Female mosquitoes require the proteins and nutrients found in the blood of their hosts in order to produce progeny. However, obtaining a blood meal from mobile and defensive hosts is not a trivial task. It requires them being able to detect, process, and evade threats posed by their predators as well as their hosts (e.g. swatts). Using LED displays, we first determined that landed *Aedes aegypti* mosquitoes exhibit an evasive response to a visual looming stimulus that mimics a rapidly approaching hand. These mosquitoes escaped looming stimuli from a wide range of angles and displayed similar evasion strategies, i.e.avoiding the line of interception of the looming object, regardless of its direction of approach. Since a major part of a mosquito's life revolves around blood feeding, we analyzed how the presence of a blood source impacts their decision making when presented with this same visual threat. For this, we introduced the

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looming stimulus to females while blood feeding on an artificial feeder to determine the extent to which the behavioral context affects their response to the stimulus. Finally, we developed new methods to record electrophysiologically from the optic lobes of mosquitoes while stimulated with visual threats. The significance of these results will be discussed in the context of their application to vector disease control tools.

74-11 Xuan, Q*; Li, C; Johns Hopkins University; *qxuan1@jhu.edu*
An energy landscape based dynamic model to simulate locomotion in complex 3-D terrain
Modeling animal locomotion in complex terrain is challenging. In a previous study, our lab developed an energy landscape approach to study locomotor transitions in complex 3-D terrain (Othayoth, Thoms, Li, 2020, *PNAS*). However, the potential energy landscape was quasi-static and did not allow prediction of dynamics. To understand and simulate transition dynamics, we developed an energy landscape based dynamic model and tested it using a system of a self-propelled ellipsoid body traversing two beam obstacles. The model simplifies the animal moving through complex 3-D terrain as a self-propelled active particle moving on a potential energy landscape in 6-D space (3-D position and 3-D orientation), whose dynamics is described by a Langevin equation. Translational and rotational acceleration of the system results from the sum of all forces and their torques. The forces include conservative forces (weight and elastic forces) described by the potential energy landscape, plus a propulsive force, a viscous force, and a random force, which model the self-propulsion, damping, and stochasticity, respectively. Conservative forces were directly calculated from the potential energy landscape gradient. Because it is challenging to calculate torques of conservative forces directly from landscape gradient using Euler angles, we used virtual rotation to calculate them from the landscape, which was verified using the body-beam interaction system. Although our dynamic model neglects collisional dynamics and assumes simple non-conservative forces, it is useful for simulating, explaining, and predicting locomotion in complex terrain. This is not only useful for understanding dynamic transitions of animals but also useful for design, control, and motion planning of robots during locomotion in complex 3-D terrain.

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22-1 Yager, CC*; Casey, CB; Vahidi, G; Jankauski, MA; Heveran, CM; Montana State University, Bozeman, Montana; *ccyager99@gmail.com*

Evaluating the modulus of flying insect thoraxes with nanoindentation

Insect flight is the product of hundreds of millions of years of evolution. However, little is known about the microscale structure and material properties of the insect thorax, a flexible exoskeleton structure that is central to the flight drive train. The objective of this research is to evaluate the thorax material properties across different insect species and within a single insect species using nanoindentation. We chose to compare thorax properties for *Manduca sexta*, a synchronous flier, and *Apis mellifera*, an asynchronous flier. Thoraxes for each type of insect were embedded in poly(methyl) methacrylate, sliced and polished in a transverse plane, and nanoindented to create modulus maps spanning the cuticle thickness in multiple locations along the thorax.Our results show that the *M. sexta* thorax has a mean modulus of 7.26 GPa ± 0.88 and that the *A. mellifera* has a mean modulus of 7.69 GPa ± 1.00. These modulus values agree with previously reported cuticle moduli for other insects (eg. Coleoptera spp).*M. sexta* also had moduli around the wing-hinge that may be unusually high for insects (~40 GPa). We imaged the thorax nanoindentation sites using Raman spectroscopy and Confocal Scanning Laser microscopy to provide insight into what may be driving these results, especially the areas with very high moduli. Preliminary results suggest that this is not the result of protein crosslinking but may be related to differences in material composition of these areas. The results of this project will help drive understanding of how thorax material may enable efficient insect flight and how material properties might change between synchronous and asynchronous lineages.

82-2 Yamaguchi, A*; Peltier, M; UNIVERSITY OF UTAH; *a.yamaguchi@utah.edu*

Conserved neural circuitry for frog vocalizations

Courtship behaviors are species-specific and function as a mechanism for reproductive isolation. The neural circuitry

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underlying courtship behavior, however, may be shared among closely-related species. Here we analyzed the neural circuitry underlying courtship vocalizations of the genus Xenopus. To attract females, male Xenopus produce courtship vocalizations that consist of clicks repeated at species-specific temporal patterns, generated by the central pattern generators (CPGs) contained in the brainstem. In Xenopus laevis, a male advertisement call contains two vocal phases, fast and slow trill with clicks repeated at a fast (~70Hz) and a slow (~30Hz) rate, respectively. Previously, we discovered that fast and slow trills of male X. laevis are produced by anatomically distinct neural circuitry in the brainstem. The fast trill CPGs rely on the ascending projection from the motor to the premotor nuclei, but not the slow trill CPGs. When the projection between the nuclei are unilaterally transected, fast trills become disorganized while slow trills remain intact. To determine a role of the ascending projections between motor and premotor nuclei in the production of courtship vocalizations in other species of Xenopus, we performed unilateral transection in X. tropicalis and X. petersii with calls made of trills containing clicks repeated at slow and fast trill rates, respectively. The results showed that vocalizations of X. petersii but not of X. tropicalis were affected by the transection, indicating that the projections between the nuclei are important for fast but not for slow trill generation in other species of Xenopus. Interestingly, the synapses between laryngeal motor neurons to premotor nuclei are glutamatergic. These results suggest that the neural circuitry for fast and slow trills is shared between species of Xenopus, although the exact vocalizations differ between the species.

S8-10 Yang, S*; Jolly, J; Cho, H; Wu, G; Fortoul, N; He, Z; Gao, Y; Jagota, A; University of Pennsylvania, Lehigh University; *shuyang@seas.upenn.edu*

Snail epiphragm inspired intrinsically reversible superglues

Adhesives are ubiquitous in daily life and industrial applications. There are two typical classes of adhesives: strong but irreversible (e.g., superglues) or reversible/re-usable but weak (e.g., pressure-sensitive adhesives and biological and biomimetic surfaces). Achieving both superstrong adhesion and reversibility has proven challenging. It has been shown that mucus secreted by

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snails allows them to maintain conformal contact with the rough surfaces of rocks or trees when they are active. Upon drying, a stiff epiphragm is formed, which interlocks with the target surface, rendering strong adhesion. Here, we report a hydrogel material system that provides superglue-like adhesion strength (up to 892 N cm^{-2}) that is also reversible. The adhesion depends on the material's intrinsic, especially, near-surface properties, and their switching in the wet vs. dry states, not its geometry; the mechanism is analogous to the action of the epiphragm of snails. It is applicable to both flat and rough target surfaces. We successfully demonstrate support of an adult human subject using two 2 cm^2 samples. We further demonstrate the flexibility to prepare a hydrogel mesh with micron-sized through-holes that can glue two nanoporous membranes together without blocking the nanochannels. We also show selective detachment of morpho butterfly wing scales using the hydrogel pad without damaging the delicate scale that has hierarchical structures, a task that would otherwise be impossible using liquid glues, further supporting the importance of low near-surface modulus during contact. We currently look to translate the knowledge into other materials to show the generosity of our biomimetic engineering principle.

105-6 Yang, Y*; Wilkinson , MG; Whitcomb, LL; Cowan, NJ; Johns Hopkins University; *yyang138@jhu.edu*

Modeling nonlinearities of refuge tracking in Eigenmmania virescens

Understanding how animals use sensory information to control locomotion is an important area of study in biology, control engineering, and robotics. The weakly electric glass knifefish *Eigenmmania virescens* is an ideal model to study sensorimotor control and integration since it naturally tries to track a one degree of freedom fore-aft moving refuge and exhibits smooth, rapid movement, allowing the analysis of how the fish converts sensory input into motor output. Previous studies applied simplified linear modeling of the controller and plant, but linear models are unable to capture the categorical differences in the fish's responses to "predictable" vs. "unpredictable" moving refuge stimuli. Specifically, previous work (Roth et al., 2011) showed that these fish track individual single sinusoidal motions much

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better than when those sinusoids were embedded in pseudo-random sum-of-sines signals. Thus, linear models used to date cannot capture the fish's real response as there are nonlinearities within the fish's controller that are revealed using different types of stimuli. Here we focus on modeling the nonlinearities of fish tracking. We first coupled a harmonic oscillator with poles at the input frequency into the fish's controller model so that the sinusoidal input can be nearly perfectly tracked at steady-state in theory. This linear control model, based on the internal model principle (IMP) in control engineering, only yields perfect tracking when the controller has an accurate model of the input frequency. However, the fish must infer the stimulus frequency in real time, adding nonlinearities to its controller. We developed a simple nonlinear control that takes advantage of the IMP, combined with a frequency identification process based on adaptive systems theory as a parsimoneous candidate that captures key elements of the nonlinear behavior, providing a more accurate model for future analyses.

68-8 Yang, Y*; Richards-Zawacki, CL; Washington University in St. Louis, MO, University of Pittsburgh, PA; *yusan.yang8@gmail.com*

Mate choice vs mate preference: Color-assortative mating pattern in a polymorphic poison frog

The codivergence of mating traits and mate preferences may generate assortative mating pattern and limit gene flow between divergent lineages in the early stages of speciation. However, this assumed behavioral isolation is effective only when assortative mate preferences lead to assortative mating patterns. Elucidating the factors mediating how preference translate to choice is thus imperative to understanding the role of divergent mate preferences in speciation. In the extremely color polytypic strawberry poison frog (*Oophaga pumilio*), female mate preferences have codiverged with color in most allopatric populations tested. However, the degree to which these divergent preferences can effect reproductive isolation in the wild is unclear. We investigated color assortative mate choice in a contact zone where a red and a blue morph co-occur naturally. When assayed in the lab, females, regardless of their own coloration, show a universal preference toward males compared to blue or phenotypically intermediate males. However, observations

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in the wild found evidence of color assortative mating: mating success in homomorphic courting pairs is significantly higher compared to heteromorphic pairs. We further used microsatellite markers to reconstruct the pedigree relationships among captured adults, juveniles, and tadpoles in a mark-recapture plot. Intriguingly, results show assortative mating tendency in red females, but not in blue or intermediate females. The discrepancies found among mate preference, mate choice, and mating pattern between the divergent red and the blue morphs of *O. pumilio* highlight the complexity of how assortative mate preference drives the evolution of reproductive isolation.

53-5 Yap, KN; Zhang, Y*; Auburn University, University of Memphis; *charlesskidd@gmail.com*

Revisiting the question of nucleated versus enucleated erythrocytes: A bird mammal comparison

Evolutionary biologists have long been intrigued by the evolution of endothermy, particularly how birds and mammals evolved endothermy independently of each other. One of the key differences between the two taxa is the presence of nucleated erythrocytes along with cellular organelles in birds, and enucleated erythrocytes without any cellular organelles in mammals. It is widely assumed that mammals evolved enucleated erythrocytes as a means to pack more haemoglobin into erythrocytes to cope with the increased aerobic metabolic demand of endothermy. However, the idea of enucleated erythrocytes having more haemoglobin per cell volume has not been tested using a phylogenetic framework. Additionally, birds evolved endothermy independently of mammals and presumably have similar selection pressure for endothermy, yet they possess not just nucleus, but also other cell organelles. To investigate whether enucleated erythrocytes have more haemoglobin per cell volume, we compared mean cell haemoglobin concentration (MCHC), along with other blood parameters of birds and mammals using a both conventional statistical approach and phylogenetic framework. Preliminary results suggest that MCHC did not differ between birds and mammals, suggesting that perhaps mammals did not extrude cell organelles from their erythrocytes to maximize intracellular haemoglobin content, and/or birds evolved a different way to maintain high MCHC. At the meeting, we will discuss some of the

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ecological and evolutionary forces that allow birds to retain nucleus and other cell organelles in their erythrocytes, as well as propose ways to test some of the hypotheses regarding the roles of different cells organelles in avian erythrocytes.

26-10 Yap, KN*; Yamada, KYH; Zikeli, SL; Zhang, Y; Zhang, Y; Kavazis, AN; Gladden, LB; Roberts, MD; Kiaris, H; Hood, WR; Auburn University, University of Memphis, University of South Carolina; *kny0004@auburn.edu*

Individual variation in cellular unfolded protein response, respiratory capacity, and stress tolerance in deer mice (Peromyscus maniculatus)

Evolutionary physiologists have long been interested in physiological mechanisms underpinning individual variation in energy metabolism and performance. Recent efforts to elucidate these mechanisms have largely focused on bioenergetics and oxidative stress. One underappreciated area that could play a role in mediating individual variation in performance is the unfolded protein response (UPR); a cellular stress response that during its adaptive phase reduces secretory protein load, enhances endoplasmic reticulum (ER) protein folding, and increases clearance capacity during homeostasis dysregulation and stress. Given that the ER and mitochondria interact closely to regulate cellular homeostasis, it seems intuitive that UPR phenotype would correlate strongly with mitochondrial physiology, which in turn would contribute to variations in whole-organism metabolism. This study aims to explore the relationship between UPR phenotype, cellular respiration, and whole-organism metabolism in deer mice (*Peromyscus maniculatus*). 33 mice were phenotyped at weaning for UPR using fibroblasts cultured from ear punches. Animals were then categorized into high UPR responders and low UPR responders. We acclimated animals to a semi-natural environment for 6 months, during which resting metabolic rate was measured. Upon termination of the study, animals were sacrificed to obtain lung tissues for fibroblast culture. Cellular respiration measurements were conducted on lung fibroblasts. Preliminary results showed that resting metabolic rates were similar between high- and low- UPR responders. Cellular metabolic rates and were marginally higher in high UPR responders. Data on cellular stress resistance will be presented.

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BSP-8-1 Yarger, AM*; Kluge, J; Siwanowicz, I; Lin, HT; Imperial College London, UK; *a.yarger@imperial.ac.uk*

Dragonfly wing mechanosensation

Flight has independently evolved multiple times, but the first known instance is the emergence of insect wings some 325M years ago. All pterygota (winged) insects, regardless of wing type or flight ability possess mechanosensory structures. These structures have evolved into several specialized classes which allow insects to detect various aerodynamic and inertial forces. An ideal group for investigating wing sensory systems are the Odonates (dragonflies and damselflies). Of the most basal pterygota insect orders, Odonata are considered the best fliers. All Odonata are aerial predators and so they must fly at least as well as the prey they consume. Using extracellular recording techniques, we measured the activity of wing nerve afferents in response to constant pressure airflow as well as in the form of various frequency sine waves. We characterized different sensors based on their activity patterns, distribution along the wing, and their preferred stimulus type. From these data, we hope to determining which forces dragonflies are capable of detecting, so that we can begin to understand how these sensory systems contribute to flight behavior and evolution.

101-8 Ye, M*; Collin, R; Chan, KYK; Swarthmore College, Smithsonian Tropical Research Institute; *mye1@swarthmore.edu*

Latitudinal pattern in microevolution rates of thermal tolerance of marine organisms

Sea surface temperature is projected to continue rising, and the ability of a species to persist largely depends on their thermal tolerance. Previous works have argued that tropical species have small thermal safety margins, and are therefore, more vulnerable to warming. One key factor in determining vulnerability is the potential of rapid evolution. Here we reviewed over 400 studies that investigate thermal tolerance of marine organisms and computed the microevolutionary rates based on existing population variance. Contrary to the notion that tropical species are more at risk, the estimated Haldane numerators from over 30 species did not show

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significant difference between geographic regions. Despite the urgency of this subject, our work also highlights the scarcity of studies that measure thermal tolerance from multiple populations. To better predict responses of marine organisms to future ocean conditions, information on both physiological limits and intra-specific variations are crucial.

S4-15 Yep, A*; Nation, JM; California Polytechnic State University San Luis Obispo; *yep@calpoly.edu*

Nuestra ciencia is our science: microbiology lessons for all

Misconceptions plague microbiology education, and most students reach college with deep-seated yet inaccurate ideas about the microbial world. Examples of misconceptions include how vaccines and antibiotics work, how viruses and bacteria cause disease, and the role of microbes in the human body and the environment. Our program tackles these misconceptions at both the elementary and college level, by tasking undergraduates with developing microbiology lessons for K-6 learners. The microbiology content is taught in Spanish at two-way immersion elementary schools, addressing another misconception: that English proficiency is a prerequisite for STEM learning. Spanish-speaking households represent 26.8% of California's population but English learners (ELs) are severely underrepresented in college and in STEM fields. ELs face discrimination and significant achievement gaps even though current understanding of the way language and science competency develop suggests that children draw on their first-language proficiency as an asset for STEM learning. Our program addresses both problems, as we work with interdisciplinary groups of undergraduates (Microbiology, Biology, Liberal Studies, and Spanish) to develop engaging experiments that illustrate microbiology concepts, which are aligned with the Next Generation Science Standards and conducted in Spanish. Lessons have accompanying resources in Spanish and English for teachers and students, including background information, handouts, and assessment tools. Besides correcting misconceptions and introducing children to role models in STEM fields, this project provides a sense of belonging and a deeper connection to their major for EL and heritage Spanish speaking undergraduates. For this paper, we

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present our program design and lessons learned from the first set of experiments piloted in Winter 2020.

37-3 Yorsz, MC*; Angelini, DR; Colby College; *mcyors22@colby.edu*
Shape Variation Within Morphs and Between Species of Soapberry Bug
The red-shouldered soapberry bug Jadera haematoloma is a species of true bug, native to the United States. The species displays a nutrition-dependent wing polyphenism, where juveniles with high food access develop short wings and greater egg-laying capacity, while individuals with lower food access develop long, functional wings and delayed egg production. Morphological variation within the two morphs has not been previously explored. Here I present geometric morphometric (GMM) analysis revealing significant shape differences within the long wing morph produced by differential food access during development. In addition, I compare J. haematoloma's wing morphology to the closely related species Jadera sanguinolenta, finding that the short wing individuals of both species have comparable wing shapes while long wing individuals have distinct ones.

27-5 Yost, CM*; Gnoose, MA; Yang, JL; Utsumi, KL; University of Wyoming, Laramie, WY, Mississippi State University, Starkville, MS, University of Southern California, Los Angeles, CA, University of Kansas, Lawrence, KS; *cydney.yost@gmail.com*
Social network analysis of two sympatric lizard species long-nosed leopard lizards (Gambelia wislizenii) and Western whiptails (Aspidoscelis tigris)
Studies on social networks illuminate social dynamics within a single species, but seldom consider interactions between species, even when species co-occur and fill similar niches. Our study focused on the social structures of two sympatric species, Long-nosed leopard lizards (*G. wislizenii*) and Western whiptails (*A. tigris*), in the Alvord Basin Desert, Oregon. Although they occupy the same habitat and consume the same prey, the species exhibit opposite forms of sexual dimorphism and rely on different foraging methods that allow them to partition niche space. To determine the extent to which interactions between the species signify an interspecific social network, we conducted focal observations and

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recorded inter- and intraspecific interactions (i.e., aggression, mating, mutual tolerance, avoidance). We characterized social networks by assessing each individual's centrality (i.e., degree, betweenness) relative to its own and to the other species. We also analyzed patterns of association within and between species relative to sex and snout-vent length and found that interactions varied within and between demographic classes, and that the two species differed in social network structure. In addition, we found intraspecific differences based on sex and body size in degree distributions and patterns of association. Interspecific interactions differed from the expectations of random networks. Our results provide evidence of a complex social structure within and between the species, which merits further study to determine the interplay between social status, interspecific relationships, and behavior.

86-8 Young, BA*; Greer, S; Cramberg, M; Kirksville College of Osteopathic Medicine; *byoung@atsu.edu*

Experimental morphology of the alligator diaphragm

In the American alligator (*Alligator mississippiensis*) the torso is subdivided by a post-pulmonary septum. Previous studies of this septum have focused on the hepatic pump; by actively regulating the contractile state of a skeletal muscle band the alligator can control the position of the liver and post-pulmonary septum, and the ventilatory pressures within the pleural cavities. The purpose of this study was to explore the morphology of the post-pulmonary septum in *Alligator mississippiensis*, and to document the pressure coupling between the pleural and peritoneal cavities of this species. The morphological investigation utilized a variety of imaging modalities, gross dissection, and histology, which revealed the presence of skeletal muscle within the post-pulmonary septum. To analyze pressure coupling, sub-adult specimens of *A. mississippiensis* were anesthetized with isoflurane then differential pressure sensors were surgically implanted into the pleural and peritoneal cavities; the outputs of these sensors were simultaneously recorded with the exhalatory gas analysis, which documented the ventilatory pattern. Using an inversion table the anesthetized alligators were tilted head-up or head-down, which generated a gravitational gradient sufficient to displace the

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liver. To further explore the pressure coupling, Veress needles were surgically implanted into the peritoneal and pleural cavities; these needles allowed positive or negative air pressure to be applied to either (or both) of the body cavities. The results of the analysis demonstrate that the post-pulmonary septum of *Alligator* is capable of coupling the peritoneal and pleural pressures, and does so at a level comparable to what has been reported for the mammalian diaphragm; the results also demonstrate that our understanding of the ventilatory mechanics of *Alligator* are incomplete.

S5-7 Young, JW*; Chadwell, BA; Dunham , NT; McNamara, A; Phelps, T; Hieronymus, TL; Shapiro, LJ; Northeast Ohio Medical University, Idaho College of Osteopathic Medicine, Cleveland Metroparks Zoo, University of Texas at Austin; *jwyoung@neomed.edu*

The stabilizing function of the tail during arboreal quadrupedalism

Arboreal mammals have longer, heavier tails than closely related terrestrial counterparts, a pattern established independently across several clades. Functionally, relatively massive tails are thought to promote stability by serving as dynamic regulators of angular momentum during precarious arboreal travel. However, empirical demonstrations of this assumed biological role remain rare. Here, we use kinematic data on primate locomotion from both the field and the lab to investigate the biomechanical function of tail usage during arboreal quadrupedalism. High-speed video analyses of 11 species of platyrrhines moving in their natural habitat show that wild arboreal primates modulate tail position in response to variation in substrate diameter and orientation (precisely measured with remote sensing). On narrower and more inclined substrates, monkeys use significantly more extended tail postures and increase overall tail displacement, consistent with the dynamic use of the tail to control whole-body angular momentum and locomotor stability. Quantitative measurements of segmental angular momenta in captive squirrel monkeys (*Saimiri boliviensis*) moving on narrow perches support this interpretation. Squirrel monkeys consistently hold their tails in extended positions throughout the gait cycle and use the large rotational inertia of the extended tail to effectively dampen trunk angular momentum

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(i.e., angular momentum cancellation = 89.5-95.4%). Collectively, these studies provide empirical support for the hypothesis that relatively long, massive tails have evolved as stabilizing organs among arboreal animals. Supported by NSF BCS-1126790, BCS-1640453, BCS-1640552, and BCS-1921314

BSP-5-7 Young, M*; Lee, J; Just, F; Angelini, D; Colby College; *mgyoun21@colby.edu*

A feature-based analysis of Bombus gut microbiomes and C. bombi infection

Champions of generalist pollination, bumblebees are remarkable for their ability to maintain a high foraging efficiency on a wide range of floral resources. Unfortunately, their once ubiquitous range is in a state of worldwide decline. Particularly disturbing is the clear importance of insect pollinators to world agriculture and our lack of replacement for their essential service. Much of recent Bombus research has focused on the importance of the microbiome community to host health. Such metataxonomic studies have uncovered sets of so called 'core microbiota' and revealed links between the abundance of these taxa and infection by pathogenic microbes. In particular, these studies have centered on the conclusion that the relative abundance of core microbiota is negatively associated with infection by Crithidia bombi, a trypanosomal parasite of bumblebees. Although informative in their own right, broader patterns of microbiome structure are lost in analyses focused around just a few taxa. To this end, methods of microbiome clustering, or 'enterotyping' have been developed in studies of human gut samples, finding distinct and stratified microbiome configurations. In this study, we present an ongoing analysis of wild-caught Bombus microbiomes. Our data was collected across the state of Maine and spans the summers of 2017-2019. Using a feature-based approach, we find distinct microbiome clusters, or enterotypes within our dataset, showing relationships with C. bombi infection. In addition, we explore the breakdown of sample metadata across our microbiome feature space, in attempt to elucidate patterns of pathogenesis on the landscape of wild bees.

101-7 Youngblood, JP*; Cease, AJ; Talal, S; Angilletta, MJ; Copa,

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F; Medina, H; Rojas, J; Trumper, E; Harrison, JF; Arizona State University, Universidad Autónoma Gabriel René Moreno, SENASA, SENAVE, Instituto Nacional de Tecnología Agropecuaria; *jpyoungb@asu.edu*

Climate warming expected to alter thermal performance and trigger range shift in outbreaking South American locusts

Ecologists use correlative models to predict how species distributions will respond to environmental change, but these models are unreliable when extrapolating to future environments. To minimize extrapolation, modelers should use mechanistic predictors that reflect range-limiting processes. As generalist herbivores with abundant food, locusts may be limited by thermal effects on digestion. We measured thermal effects on the consumption and defecation of South American locusts (Schistocerca cancellata), and we used these data to project performance in current and future climates. We then integrated the performance projections into species distribution models to predict the distribution of outbreaking locusts based on different predictor sets, modelling methods, and climate scenarios. Contrary to expectations, models with only mechanistic predictors performed worse than those with only macroclimatic predictors; however, the best models were those that used both predictor types. Based on the mechanistic model, these locusts should occur throughout tropical S. America, but species distribution modelling revealed they are restricted to temperate regions. This mismatch between the mechanistic model and the distribution of S. cancellata suggests that the northern range of this species is limited by some factor other than temperature. All models projected that locusts would shift to higher latitudes and altitudes in response to climate warming, with the magnitude of this shift proportional to the amount of warming. Consequently, agriculturists should consider enhanced monitoring and management near the southern range of this species. Partially supported by NSF IOS 1826848.

25-9 Zack, EH*; Smith, SM; Angielczyk, KD; University of Chicago, The Field Museum of Natural History , The Field Museum of Natural History, University of Chicago; *ehzack@uchicago.edu*

Effects of captivity on the bone microstructure of xenarthrous vertebrae

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Captive specimens in natural history collections allow researchers to inspect the morphologies of rare taxa, but the lifestyles, diets, and lifespans of captive animals differ from those of their wild counterparts. To quantify these differences, we compared bone microstructure of trunk vertebrae in captive and wild xenarthran mammals (sloths, armadillos, anteaters). Because trabecular bone architecture (TBA) adapts to in vivo forces, bone microstructure reflects ecology and behavior, but this means that it may differ between captive and wild specimens of the same species. We collected μCT scans of the last six presacral vertebrae in 13 species of fossorial, terrestrial, and suspensorial xenarthrans ranging in body mass from 120g (*Chlamyphorus*) to 35kg (*Myrmecophaga*). For each vertebra, we measured bone volume fraction (BVF); trabecular number, mean thickness (TbTh), and orientation; global compactness; and cross sectional area. Wild specimens generally have more robust trabeculae, but this differs based on species, vertebral position, ecology, and pathology. The wild specimens of fossorial taxa (*Dasypus*) have more robust trabeculae than their captive counterparts, but there is no clear difference in TBA of wild and captive specimens in suspensorial and terrestrial taxa (*Bradypus*, *Choloepus*, *Cyclopes*). These data suggest that locomotor ecology affects the level to which captivity affects bone microstructure. The captive specimens of both *Tamandua* and *Myrmecophaga* have higher BVF and TbTh than their wild counterparts, indicating more brittle trabeculae due to bone pathologies caused by captivity. Our results add to the overall understanding of variation in mammalian bone microstructure and suggest caution when including captive specimens in research on TBA.

109-2 Zagkle, E*; Grosiak, M; Bauchinger, U; Sadowska, ET; Jagiellonian University, Institute of Environmental Sciences, Krakow, Poland; *elisavet.zagkle@doctoral.uj.edu.pl*

Age-related differences in core body temperature and oxidative stress under limited food availability

In endotherms, maintenance of constant body temperature can be challenging under limited food availability. Many birds may drop body temperature below normothermia during the night to decrease energy metabolism. Such rest-phase hypothermia may also affect the

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level of oxidative stress due to the positive link between metabolism and reactive oxygen species. Aging may impair thermoregulatory capacity, but until today age-specific rest-phase hypothermic responses and their potential effect on oxidative stress have never been investigated. We challenged 25 zebra finches (Taeniopygia guttata) of three age groups (young, middle-aged, old) by limiting access to food for one day or provided them normal access to food. We compared body temperature through implanted data loggers and quantified oxidative stress in the morning. We found age-related differences during rest-phase hypothermia, while all three age groups remained normothermic in the night following a day with access to food. Old birds revealed the lower body temperature during night and the highest levels of oxidative damage in the following morning, while young and middle-aged birds showed higher night-time body temperature and lower values of oxidative damage. Our results lead us to propose a novel hypothesis on how aging may lead to an accumulation of oxidative damage; impairment in thermoregulatory capacity with advancing age increases the risk of oxidative stress, but only under challenging conditions. Research funded through NCN grant 2016/22/E/NZ8/00416 to ETS.

BSP-10-4 Zapfe, KL*; Hodge, JR; Larouche, O; Friedman, ST; Wainwright, PC; Price, SA; Clemson University, Rice University, Yale University, University of California Davis; *klzapfe@ncsu.edu*
The evolution of bold color patterns across teleost fishes
Fishes include some of the most visually striking vertebrate radiations and have repeatedly evolved bold color patterns, including bars, stripes, and spots. Such strong color patterns are hypothesized to provide multiple functions, including avoiding predation by obscuring recognizable features and communicating with others to secure territory and mates. Despite increasing interest in the function of these color patterns, our current understanding of the evolution of these patterns remains limited. Specifically, the macroevolutionary dynamics remain under explored and consequently we lack an understanding of how evolutionary history influences color patterns and whether color pattern elements coevolve. To address these questions, we examine the evolutionary lability of color pattern types and quantify potential coevolutionary relationships between pattern elements across 6000+

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teleost fishes. In addition, we test the long-held assumption that reef fishes are more patterned than their non reef-dwelling marine relatives. We scored species for the presence of color pattern elements (e.g. eye stripe, body spot) using photographs of museum specimens cross-referenced with live photos when necessary. We then applied evolutionary models to estimate pattern element lability and test for the coevolution of pattern elements using a phylogenetic comparative framework. Our preliminary results indicate that patterns with multiple bars evolve more frequently than those with a single bar and conversely, patterns with multiple stripes evolve less often than single stripe patterns. We therefore conclude that bar and stripe elements have different tempos and perhaps even modes of evolution, suggesting that, over macroevolutionary timescales some pattern elements are more easily changed than others.

29-5 Zaragoza, G*; Fitak, RR; Robson, C; University of Central Florida; *george.zaragoza@knights.ucf.edu*

Assigning rural and urban origin to burrowing owls (Athene cunicularia) using traditionally omitted genomic data

Urbanization in wildlife often occurs as a few individuals from rural environments migrate to an urban setting. Within burrowing owls (*Athene cunicularia*), urbanization has led to numerous consequences including the reduction of fear responses to human presence and the loss of rare alleles. Recent genomic analyses of burrowing owls have also implicated selection on various neuronal and synaptic genes in response to urbanization, linking the transition to urban environments to changes in cognitive function. However, genomic analyses are often computationally intensive, require samples with high quality DNA, and omit a large proportion of DNA sequencing data that cannot be accurately assigned to the draft reference genome. Here, we utilize this proportion of unused data and associate it with environmental variables to assign individual burrowing owls to either urban or rural origin. Our goal is to develop a tool for characterizing the DNA from burrowing owls using only a few short target sequences as predictors. This work will also aid in identifying previously unknown sequences associated with urban and rural environments. Additionally, knowledge of these sequences will allow for the rapid

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characterization of burrowing owls sampled across the urban-rural landscape to improve our understanding of their range, dispersal, and the effects of urbanization for conservation efforts.

S4-8 Zavaleta, E*; Beltran, R; Race, A; University of California, Santa Cruz; *zavaleta@ucsc.edu*

How and why does a field course close demographic gaps in EEB?

Field courses have been identified as powerful tools for student success in science, but the potential for field courses to address demographic disparities in science is little-explored. We examined (a) effects of an introductory field course on students' perception of their scientific competencies, and (b) how the field course shaped student experiences and built their sense of community, confidence and belonging in science. We focused on a non-majors EEB course, Introduction to Field Research, at the University of California-Santa Cruz (UCSC), a large Hispanic-Serving Institution. Our mixed-methods approach included pre- and post- course surveys with field course students and a control group; interviews, focus groups and prompted student journal entries with a subset of field course students; and participant-observation in a fall 2019 offering of the course. We found that field course participation in general at UCSC was associated with higher science self-efficacy gains, GPA and graduation rates. Students who took Introduction to Field Research experienced especially large science self-efficacy gains if they started with low self-assessed science competencies. As a result, the course closed science confidence gaps between students from marginalized and well-represented groups. Themes of growth in peer community, relationships with mentors, confidence living and working outdoors, team-based science skills and experience, and a sense of contributing to knowledge and discovery interacted throughout the course - especially from the initial overnight field trip to the final one - to yield these confidence gains and cement interest in science careers or incorporation of science into other disciplines. We discuss how field course design and implementation can enhance inclusion, reduce demographic gaps in science, and inspire students to pursue collective discovery and excellence in their academic careers.

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51-2 Zelditch, ML*; Swiderski, DL; University of Michigan, Ann Arbor; *zelditch@umich.edu*

Integrating adaptive with geographic landscapes: Trophic morphology of desert rodent assemblages

Adaptive landscapes are a central metaphor for understanding the dynamics of morphological evolution, but geographic landscapes are central to understanding how morphological diversity persists. In this analysis, we revisit a classic paradigm for community assembly in light of the adaptive landscape of desert-adapted rodents (Heteromyidae). Traditionally, these rodents are considered to belong to a single dietary guild, divisible into two functional groups by locomotory mode. According to the model for their community assembly, increases in species richness occur by packing more ecologically similar species into more diverse communities. That model predicts that functional diversity would not consistently increase with species richness, an expectation supported by analysis of phylogenetic community structure, which found that more close relatives are packed into richer communities. Revisiting this case, we integrate an analysis of the adaptive landscape of trophic morphology with an analysis of the geographic patterns of morphological and phylogenetic diversity. We also find that, at a scale of 5 km resolution, richer assemblages consist of closer relatives: as expected, most metrics of phylogenetic diversity negatively scale with species richness. However, the scaling relationships for morphological measures of diversity supply a different explanation: the morphological range and minimum nearest-neighbor distances exhibit contrasting scaling relationships: the range of morphology increases, although not at a constant rate, as the minimum nearest-neighbor distance decreases. With respect to dietary adaptations, local assemblages of heteromyids apparently exhibit a combination of niche-expansion and finer partitioning.

23-1 Zeng, Y*; Petrichko, S; Nieders, K; Fudge, D; Chapman University; *yzeng@chapman.edu*

Scaling of secretory cells and cell products with body size in hagfishes

The size of animal cells is generally constrained by physiological and developmental factors and rarely scales with body size. Cell

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size can potentially be influenced by other selective factors that act upon the performance of cell products. In hagfishes, slime gland thread cells (GTC) produce and store threads, proteinaceous fibers that provide strength to their defensive slime. Here, we addressed the scaling of GTC size and thread size with body size by sampling from 20+ species of hagfishes. We found that the maximum GTC length, ranging between 100 - 250 μm, was positively correlated with body size, which varied between 15 - 70 cm in our samples. Despite the size variation, the length to width ratio of GTCs was relatively conserved. Larger GTCs possessed disproportionally thicker threads, the diameter of which increased by four-fold over the range of GTC sizes we examined. A simplified geometric model further suggests that larger hagfishes produce stiffer and stronger slime, with slime threads that are shorter relative to their body length. These results provide insights for understanding the development and evolution of slime threads in hagfishes. This study provides an example of selection on a secreted cell product influencing the evolution of cell size.

93-10 Zhang, S*; Gray, JR; University of Saskatchewan, Saskatoon, SK, Canada; *sinan.zhang@usask.ca*

Population coding of visual motion detection and control of avoidance behaviours in locusts

Locusts are capable of performing complicated flying maneuvers, which relies on rapid detection of moving objects present in the surroundings to generate appropriate behavioural responses. An identified neural pathway, comprised of the LGMD (lobula giant motion detector) and the DCMD (descending contralateral motion detector), responds preferentially to approaching objects. LGMD receives retinotopic inputs from ipsilateral ommatidia and generates spikes in a 1:1 ratio in the DCMD, which synapses with multiple locomotion-related neurons. As an angular threshold detector, the DCMD has been implicated as critical for initiating evasive behaviours, although its specific role remains to be fully described. Importantly, numerous other motion-sensitive neurons have also been identified in locusts. These neurons have distinct firing properties and response preferences. Information from these neurons likely contributes to production of avoidance behaviour. However, few studies have investigated the contribution of these

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neurons on a neural population level. To better understand how visual information is perceived by locusts, we constructed a multichannel recording system within an existing flight simulator and presented various complex visual stimuli to rigidly tethered locusts. Preliminary analyses have identified functional units that responded to visual stimuli. Common trends, which reflect the activity of neural ensembles, were extracted from these functional units. These common trends were compared under different conditions to reveal how is the population coding is modulated dynamically.

29-9 Zhang, P*; Jacobs, D; University of California, Los Angeles; *pzhang312@ucla.edu*

Evolution of DNA methylation in Cnidaria

The extent and pattern of DNA methylation on different genomic elements vary greatly across Metazoa; in particular, bilaterian vertebrates and invertebrates show striking differences regarding methylation on the gene bodies. It has been hypothesized that gene body methylation is the ancestral state for Metazoa; however, sampling outside of Bilateria is minimal. From this perspective, we survey 76 Cnidarian species spanning all major groups using computational methods to probe the extent of DNA methylation, and we show that methylation on the gene bodies is prevalent in Cnidaria, with a few instances of loss. We also show that gene body methylation correlates with sequence conservation and expression variability. Notably, several species show derived methylation status on orthologous genes. In addition, gene bodies are preferentially targeted over repetitive elements, and both gene body methylation and repeat methylation change with repeat content. Taken together with evidence from other Metazoan taxa, this work supports the hypothesis that methylation preferably targeting gene bodies, not regulatory sequences or repetitive elements, was the ancestral state for Metazoa.

45-10 Zhang, Y; Yap, KN; David, KT; Swanson, DL*; University of Memphis, Auburn University, University of South Dakota; *david.swanson@usd.edu*

Does the high-energy aerial insectivore lifestyle of swallows produce thermogenic side effects?

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Life-history traits related to pace of life, such as foraging strategies and activity levels, influence daily energy expenditure and can affect fitness. Lifestyles supported by high-energy aerobic activity result in daily energy expenditure and basal and maximal metabolic rates in some endotherms. Maximal capacities for exercise and thermogenesis are both functions of aerobic muscle output, so high activity-lifestyles might be expected to produce high thermogenic capacities as a by-product. We tested whether the high-energy aerial insectivore lifestyle in swallows is correlated with elevated basal and maximal thermogenic metabolic rates. We measured basal (BMR) and summit (Msum = maximum cold-induced metabolic rate) metabolic rates in six species of swallows and combined these data with literature data to address the hypothesis that swallows have higher BMR and Msum than non-aerial insectivore birds. BMR in swallows was significantly higher than for non-aerial insectivores for both conventional and phylogenetically adjusted analyses after correcting for body mass and region of origin (tropical vs. temperate). In contrast, Msum did not differ significantly between swallows and non-aerial insectivores. Thermogenic scope (Msum - BMR), however, was elevated in swallows relative to non-aerial insectivore birds. This latter result was driven mostly by elevated scope in tropical swallows relative to tropical non-aerial insectivores, suggesting that the aerial insectivore lifestyle limits reductions in thermogenic scope typical of tropical birds. Thus, swallows maintain a higher BMR than non-aerial insectivore birds, but maximum thermogenic capacities are not similarly upregulated, suggesting that the high-energy aerial insectivore lifestyle does not produce strong thermogenic side effects in this taxon.

BSP-3-5 Zhang, VY*; Buck, CL; Northern Arizona University, Department of Biological Sciences, Flagstaff, AZ 86011; *vyz3@nau.edu*

The ecophysiology of tassel-eared squirrels and its relationship to food, weather, and reproduction

Ecological specialization is suggested to impede the ability of species to respond to environmental changes. Tassel-eared squirrels are specialists of the ponderosa pine habitat, encountering naturally high levels of climate and resource variability across

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the year. Using collar-mounted accelerometer and GPS devices, we assessed the relative importance of weather and reproduction in determining levels of activity in a natural versus suburban (food supplemented) population of tassel-eared squirrels. In addition, we measured fecal metabolites of testosterone, estradiol, progesterone, and cortisol in squirrels to non-invasively assess patterns in reproductive timing, hormonal correlates of behavior, and glucocorticoid secretion between individuals and populations. While weather was a strong predictor of daily activity levels in both populations, seasonal variation in activity levels were more attenuated in squirrels from the suburban site when compared to the natural site. Furthermore, home range size remained relatively stable across the year at the suburban site but fluctuated seasonally at the natural site. Hormone analyses and field observations suggest that populations did not differ in reproductive timing or patterns of seasonal weight gain; however, we found higher cortisol and lower testosterone levels in the natural compared to suburban populations. Lastly, we found no relationships between testosterone/cortisol and indices of animal behavior. Taken together, the activity patterns of squirrels appear to be primarily driven by weather and seasonal fluctuations in food availability. Comparisons between sites suggest that anthropogenic food sources may drive endocrine and behavioral changes associated with a central place foraging strategy.

70-10 Zhang, D*; Wang, Y; Lauderdale, LK; Gabaldon, J; Miller, LJ; Barton, K; Shorter, KA; University of Michigan, Ann Arbor, MI, Chicago Zoological Society, Brookfield, IL, Chicago Zoological Society, Brookfield, IL; *zhding@umich.edu*

A data driven approach for estimating hydrodynamic drag of bottlenose dolphins

Accurate estimation of hydrodynamic drag experienced during locomotion is an important parameter for the study of dolphin swimming biomechanics. Model based approaches have been used to estimate drag force. However, kinematic data for these estimates tends to be limited to a relatively small number of swimming events. This work estimates drag acting on a gliding bottlenose dolphin (*Tursiops truncatus*) using a dynamic model of the animal motion and tag based measurements of swimming kinematics. A data

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driven approach was used to mine qualified animal gliding segments from 84 hours of biologging tag data from three animals. Using this approach, we were able to identify 532 gliding events over a range of swimming speeds (1 m/s to 5 m/s), an order of magnitude more data than some comparable studies in the literature. The identified drag coefficients cover a wide range of speeds and compare well with other published results. Importantly, the results indicate that swimming dolphins could experience 2.1 times more drag during low amplitude fluking than gliding at the Reynolds number of 4.263 x 10^6 (equivalent to traveling speed of 1.8 m/s with animal body length of 2.5 m), which speaks to the energetic benefits of employing a fluke-and-glide gait pattern as opposed to continuous fluking. While this work presents results from bottlenose dolphin swimming data, the method can be applied to other cetaceans in various environments as long as speed can be measured/estimated accurately.

79-9 Zhang, Z*; Zhang, D; Gabaldon, J; West, N; Barton, K; Shorter, KA; University of Michigan, Ann Arbor, MI, Dolphin Quest, Oahu, HI; *znzhang@umich.edu*

Analysis of environment dependent locomotion of bottlenose dolphins using Mask R-CNN

How environmental features (e.g. people or other animals) affect movement is an important element for the study of animal behavior, biomechanics and welfare. Here we present a stationary overhead camera-based persistent monitoring framework for the investigation of bottlenose dolphins (Tursiops truncatus) response to environmental stimulus. Mask R-CNN, a convolutional neural network architecture, was trained to detect 3 types of targets in the environment: dolphins, people, and enrichment floats intended to stimulate and engage the animals. Detected targets within each video frame were linked together to create track segments across frames. The animal tracks were used to parameterize animal response to the presence of environmental stimuli. We collected and analyzed over 10 hours of data, 4 hours with and 6 hours without enrichment, from animals in a manage lagoon environment. With no enrichment present, animals swam with an average speed of 1.08 m/s, and tended to be attracted to areas of the environment with people present. Floating enrichment in the environment created a dynamic point of

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attraction, lowering the average swimming speed to 0.64m/s and modifying the use of the full environment. These preliminary results indicate that the presence of enrichment and people in, or around, the environment attract the animals, biasing habitat use and movement patterns as a result. This work demonstrates the ability of the proposed framework for the quantification and persistent monitoring of bottlenose dolphins, and will enable new studies to investigate individual and group animal locomotion and behavior.

97-13 Zhao, A*; Iyer, N; Kim, E; Reiser, M;
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An outside-in comparative study of visual systems in the Drosophila melanogaster subgroup

The elaborate courtship rituals of many fly species have been studied in some detail. Specific roles for multiple sensory systems, including olfaction, audition, and vision, have been described, with vision receiving the least attention in recent studies. While there is much to see during a courtship "dance", these interactions have often been described from the perspective of the observing scientist, and not carefully considered from the vantage of a courting male or an evading female fly. In *Drosophila melanogaster* it has been proposed that male flies use vision to track the female's head, abdomen, and extended wing location, and to judge the receptivity of females based on their locomotion. However, it is not clear whether (or how much) visual signals are used to determine if the courtship target is a member of the same species. For species that are similar in size, the conspecific is likely identified primarily via other modalities, although it is also likely that flies use vision to exclude false target, either by size or appearance. In order to estimate the visual capabilities of different, closely related species, we have undertaken a comparative anatomical study of the eyes of three species in the *Drosophila melanogaster* subgroup (*D. melanogaster, D. simulans* and *D. mauritiana*). We use micro-CT technology to image the entire optical apparatus in a single isotropic image volume with single-photoreceptor level resolution. In particular, this allows us to measure the resolution, viewing directions, visual acuity, and zone of binocular overlap. We will present a comparison

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of these eye maps across these three species, while also comparing males to females of each species. Based on our detailed understanding of the D. melanogaster visual system, we will speculate about how the sibling species' vision may differ and make predictions about the possible function of vision in courtship.

74-1 Zhao, W*; Ayala, J; Schulz, A; Rong, H; McGowan, C; Hu, D; Georgia Tech, School of Mechanical Engineering, Atlanta, GA, Chengdu Research Base of Giant Panda Breeding , University of Idaho, School of Biological Sciences, Moscow, ID, Georgia Tech, Schools of Mechanical Engineering and Biological Sciences, Atlanta, GA; *wenxinrosezhao@gatech.edu*

Juvenile pandas use head motion to maintain balance during climbing

A juvenile panda's best defense against predators is to scamper up a tree. Compared to other members of the Ursidae family, Giant Pandas (*Ailuropoda melanoleuca*) have the smallest shoulder height to body weight ratio, suggesting a weak climbing ability. In this experimental study, we film eight panda cubs climbing poles of various diameter. Cubs climb at speeds of 0.1 - 0.2 body lengths per second, which is 16 times slower than scansorial primates of similar mass. While all climbing pandas swung their heads laterally at a rate of 0.4 Hz, successful climbers swung their heads at twice the amplitude of failed climbers. We hypothesize that wider head swings enable pandas to maintain torque balance as they lift and extend each foreleg. Our study provides quantitative metric for climbing ability, to aid the selection of pandas for reintroduction.

74-10 Zheng, B*; Xuan, Q; LI, C; Johns Hopkins University; *bzheng8@jhu.edu*

Stochastic dynamics model statistically predicts beam obstacle traversal

Animals are excellent at traversing obstacles in complex terrain by transitioning between locomotor modes. Our recent studies demonstrated that a potential energy landscape approach help understand how animals and robots transition between modes (Othayoth, Thoms, Li, 2020, PNAS). In that study, obstacles were

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uniform; however, in the real world, obstacles often vary spatially. In addition, our previous energy landscape model was quasi-static and did not capture stochastic dynamics common in locomotion. Here, we take the next step in establishing the energy landscape approach to locomotor transitions. We developed a stochastic dynamics simulation by applying the Langevin equation on a simplistic 2-D model system, a self-propelled circular body traversing two adjacent horizontal elastic beam obstacles on a flat ground, with one beam stiffer than the other. Body-beam interaction was determined by calculating collisional dynamics between rigid bodies and the gradient of the system's potential energy landscape which describes elastic forces during continuous contact. On the landscape, the resistance of the two beam obstacles resulted in a potential energy barrier on each side, and the body could be trapped in an attractive basin in front of them. We found that increasing random force and self-propulsive force increased the body's probability to escape from the basin and overcome a barrier to traverse. In addition, with one beam stiffer than the other, the body had a higher probability to escape by moving along trajectories that overcame the lower barrier. Our simple model was a proof of concept that potential energy landscapes can help statistically predict the distribution of trajectories of a self-propelled body traversing obstacles, which will be useful for control and motion planning of robots to traverse complex terrain.

73-5 Zhong, B*; Goldman, D; Bergmann, P; Goergia Tech, Clark University; *baxichong8@gmail.com*

Body-leg coordination in lizard locomotion along the body elongation and limb reduction continuum

One of the best-documented transitions in vertebrate evolution is from a short-bodied, robustly-limbed, pentadactyl form to an elongate, limbless, snake-like form. Such transition is gradual and in some cases, extant intermediate species exist for millions of years. How can these intermediate species do well? One of the possible aspects is how these animals coordinate limb and body movements, combining running via limb propulsion and swimming via body undulation. In this paper, we studied the locomotion pattern of three species of Brachymeles skinks (*B. kadwa with hind leg lengths (HLL) = 0.17±0.02 snout-vent length (SVL), B. taylori with*

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HLL = 0.15±0.02 SVL, and B. mungtingkamay with the HLL = 0.09±0.01 SVL) and compared it with the stereotypical lizard, Uma scoparia (HLL = 0.25±0.03 SVL), and the legless lizard, Lerista praepedita. We use new theoretical tools including geometric mechanics and neural net trackers to explain and analyze how they can make forward progress on sand surface via appropriate coordination of aforementioned locomotion modes. Our numerical model shows that both leg movements and body undulation contribute to generating self-propulsion in the intermediate species. Moreover, the body-leg coordination observed in these intermediate species quantitatively agrees with theoretical predictions from our modeling to optimize forward speed. Although evolutionary pressures can shrink limbs and elongate bodies, motor control systems can flexibly accommodate these changes to generate appropriate limb-body coordination for high locomotion performance.

43-5 Zimmer, C*; Hanson , HE; Martin, LB; University of South Florida, Tampa; *cedriczimmer@usf.edu*

How FKBP5 expression is affected by acute and chronic stress and relates to glucocorticoids levels in house sparrows

Stress resilience, an individual's ability to recover from or to maintain normal activities despite stressor exposure, is critical for fitness and in many cases relates to HPA flexibility or the rapid reversible plasticity in HPA axis function. A co-chaperone molecule involved in glucocorticoid receptor activity, *FKBP5*, may mediate HPA flexibility and stress resilience because it affects how individuals can regulate glucocorticoids (GCs) and capacitate their ability to adjust phenotypes appropriately to adverse conditions. Although well-studied in the biomedical field, *FKBP5* research on wild vertebrates is limited. Here, we asked about the role of *FKBP5* in coping with adversity in a wild species. We exposed house sparrows (*Passer domesticus*) to 20 days of a chronic stress protocol, while others were only exposed to daily husbandry. At capture and after the chronic stress protocol, we measured baseline, stress induced, and negative feedback levels of GCs. In the blood, we measured *FKBP5* expression and GC level at both time points. At the end of the experiment, we measured *FKBP5* expression in the hippocampus and hypothalamus. We hypothesized that *FKBP5* expression in the blood would correlate

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with expression in these tissues. We expected that *FKBP5* expression would increase in response to acute stress but more so to chronic stress. We also hypothesized that individuals which had a smaller increase in *FKBP5* expression would have higher HPA flexibility allowing them to adjust their GC response to the current conditions. We supposed that individuals with higher HPA flexibility would cope better with current conditions suggesting higher stress resilience and that *FKBP5* is a key mediator of HPA axis flexibility.

111-5 Zinck, NW*; Jeradi, S; Franz-Odendaal, TA; Dalhousie University, Mount Saint Vincent University, Mount Saint Vincent University; *nc966938@dal.ca*

Pharmaceutical inhibition of BMP signaling pathway severely disrupts cartilage morphology during zebrafish larval development

Vertebrate cartilage development requires a tight regulation to ensure the proper differentiation and morphology of various cartilaginous elements. The bone morphogenetic protein (BMP) signaling pathway is highly involved in regulating cartilage morphogenesis. In this study, zebrafish larvae were exposed to a pharmaceutical BMP inhibitor, LDN193189, prior to the development of two cartilage structures: the scleral cartilage and the caudal fin endoskeleton. BMP inhibition had no effect on the scleral cartilage, while severe morphological disruptions were apparent in the caudal fin, as determined via wholemount bone and cartilage staining. The disrupted fin cartilage phenotype was characterized and quantified using morphometric techniques and principal component analysis. Using in-situ hybridization, we further confirmed that BMP inhibition caused a reduced expression of sox9, a well-known cartilage development master regulator. This study is one of the first to utilize LDN193189 to study zebrafish cartilage development, and our results shine a light on the different regulatory systems at play in the development of different cartilage elements. Additionally, this study adds to our knowledge of caudal fin development and evolution.

78-1 Zinßmeister , D; Sapir, N*; University of Haifa, Haifa, Israel; *nirs@sci.haifa.ac.il*

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Passerine stopover strategy at a desert edge depends on the time it takes to start accumulating fuel before departure

Theoretical predictions suggest that fuel deposition rate (FDR) is an important attribute of migrating birds during stopover, specifically predicting that higher FDR induces longer stopover and higher departure fuel load (DFL). We explored bird stopover behavior, fuel deposition and departure timing in fall migrating Red-backed shrikes (*Lanius collurio*) that stopped-over in the Hula Valley of Northern Israel from where they undertake a long journey of about 2,000 km across the Sahara Desert. During the falls of 2017 and 2018 we made daily censuses, trapped birds in the field and tracked their movement by the ATLAS time-difference-of-arrival radio-telemetry system. Using field deployed scales, we remotely measured bird body mass (n = 15 individuals) on a daily basis. Surprisingly, we found that the staging birds were composed of two groups of birds that predominantly differed in the time period before starting to continuously increase their body mass before departing (group 1: range 2-3 days, n = 6, hereafter "short" ; and group 2: range 9-13 days, n = 9, hereafter "long"), as well as their total stopover duration. Notably, key stopover properties differed between the two groups. For example the relationship between FDR and stopover duration was positive in the "short" group and negative in the "long" group, and the relationship between FDR and DFL were nearly constant in the "short" group and positive in the "long" group. These findings suggest that prolonged periods without continuous fueling are common when staging near edges of wide ecological barriers, with critical consequences for stopover strategy.

35-8 Zipple, MN*; Southworth, CA; Clinton, SP; Archie, EA; Alberts, SC; Duke University, University of Notre Dame; *matthew.zipple@duke.edu*

Determinants and influences of infant spatial relationships with adult males in wild baboons: a mechanism for intergenerational transmission of early adversity?

A primate infant's experience during early life is heavily influenced by characteristics of its biotic environment, including characteristics of its mother and its broader social environment. For example, infant baboons are more likely to die if their mothers

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experienced high levels of early life adversity. These intergenerational effects may be mediated by differences in the social environment experienced by infants born to mothers that experienced high levels of early adversity. Adult males play an especially important role in infants' experience by providing protection and a zone of relative safety in which an infant can develop. Here we present the most detailed analysis to date of the determinants of the immediate adult male social environment that infants experience and the influences of adult males on a wide range of infant behaviors. We show that the average number of adult males within 5m of infant baboons is significantly repeatable over time ($R = 0.15$) and that this repeatability is partially explained by the levels of early life adversity experienced by the infant's mother. We also show that the number of adult males in close proximity to an infant predicts a wide range of fundamental infant behavioral traits, including the mother-infant spatial relationship, infant activity budgets, and the frequency of both positive and negative social interactions with non-mothers. Our results are consistent with the possibility that the effects of maternal early life adversity can be transmitted, in part, via differences in the early life social environments that infants of high-adversity mothers experience.

85-6 Zlotnik, S*; Allen, PE; Miller, CW; University of Florida, Council on International Education Exchange; *zlotniks@ufl.edu*
Morphological plasticity, not social behavior, may maintain diet breadth in leaf-footed bugs
Generalist-feeding animals must overcome a wide range of defenses in the species that they consume. In particular, structural feeding barriers in plants pose major challenges to generalist herbivores, and it is unclear what adaptations enable them to surpass these barriers. Understanding the feeding strategies used by generalist herbivores, as well as their limitations, is important for predicting future range shifts of introduced species as well as other species of economic or ecological concern. We investigated how two strategies, developmental plasticity and social feeding behavior, may contribute to diet breadth in western leaf-footed bugs, *Leptoglossus zonatus* (Hemiptera: Coreidae). To test the role of plasticity in diet breadth, we raised bugs on a diet of

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sunflower seeds covered with either a thin or a thick artificial coating and measured their mouthpart morphology at adulthood. We found that bugs raised on seeds with a thick coating had relatively longer mouthparts, indicating likely diet-induced plasticity. To test how social behavior contributes to diet breadth, we raised bugs with either an adult or a juvenile conspecific on a diet of pecans with or without shells. Juvenile bugs may reuse the feeding sites of larger conspecifics to facilitate feeding through barriers. We therefore predicted that bugs feeding on pecans with shells would have higher survival when housed with an adult than with another juvenile. Surprisingly, we found that juvenile survival was severely limited by pecan shells and the presence of adults did not ameliorate this effect. Our results suggest that morphological plasticity, but not social behavior, facilitates feeding and could function to maintain diet breadth in *L. zonatus*.

98-4 Zobek, CM*; D'Amore, D; Dillman, CB; Cornell University, Ithaca, NY, Daemen College, Amherst, NY; *cmz33@cornell.edu*
Morphological adaptations of the skull and teeth in kingsnakes (Serpentes: Colubridae) for skink predation
The ability to capture and hold specific prey is likely under strong selective pressure and should allow for predictable convergent modifications. Skinks are difficult prey to capture due to their hard scales, and examples of specializations for scincivory abound within Serpentes. However, direct comparisons between related specialists or quantified intraspecific differences have not been attempted. A model system would contain several taxa with various diet specializations, such as the genus *Lampropeltis*. *Lampropeltis elapsoides* is a skink specialist, while diet across the subspecies of *Lampropeltis triangulum* are variable. *Lampropeltis triangulum syspila* shifts from ectotherms to a generalist diet over ontogeny, while *Lampropeltis triangulum triangulum* ingests endotherms throughout. We utilized preserved specimens and computerized tomography to compare teeth across ontogeny and quantified the size and shape variation using semilandmark analysis to test for dietary specializations. There is significant change in tooth size and size-disparity in all three taxa at a specific body size, with consistent specializations shown in quantified tooth shape and jaw descriptions in smaller snakes.

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This suggests an ontogenetic transition that correlates to a change in diet away from scincivory that is consistent with the dietary hypothesis for *L. elapsoides* and *L. t. syspila*. These data suggest heterochrony can explain the specializations of *L. elapsoides*; it has a smaller maximum size and maintains specializations throughout its life, whereas *L. t. syspila* transitions its diet at a larger size. Dietary observations in *Lampropeltis t. triangulum* could be explained by an unknown dietary shift or ancestral condition.

S6-13 Zornik, E*; Barkan, CL; Descant, KD; Lloyd-Burchett, P; Leininger, EC; Reed College, New College of Florida; *ezornik@reed.edu*

Everything in modulation: neuromodulators as keys to understanding behavioral dynamics

Animal communication serves a wide range of functions, such as defending territories and attracting mates. Producing the appropriate signals for each social encounter is essential, but how communication behaviors are selected and adjusted in a context-dependent manner is poorly understood. This question can be addressed on many levels, including sensory processing by peripheral organs and the CNS, sensorimotor integration in decision-making brain regions, and motor circuit activation and modulation. Because neuromodulator systems are able to adjust outcomes at each of these levels, they are a useful lens through which to explore the mechanisms underlying complex patterns of communication. It has been clear for several decades that understanding the logic of input-output decision making by the nervous system requires much more than simply identifying the connections that link sensory organs to motor circuits; this is due in part to the fact that neuromodulators can promote distinct and temporally dynamic responses to similar signals. The role of neuromodulators in regulating motor output of central pattern generators is well established, however, combinatorial actions of multiple neuromodulatory substances are often overlooked. We review the complex roles of neuromodulators in diverse behaviors with the goal of applying those lessons to the study of communication. We argue that identifying the full suite of neuromodulators involved in regulating behavioral circuits at any level of control, from sensory organs to motor circuits, may be a necessary first step

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toward a fine-scale understanding of how behavioral context elicits appropriate communication signals.

82-10 Zung, JL*; McBride, CS; Princeton University; *jessica.zung@princeton.edu*
Characterizing vertebrate odor space
Understanding how animals use sensory information in the environment requires knowing the structure of the relevant stimulus space in nature. For instance, vision researchers must examine how often specific colors and patterns occur in relevant stimuli. Characterizing olfactory stimuli is especially difficult. A given stimulus could comprise hundreds of individual compounds, each of which might be considered its own dimension in odor space. Trapping and analyzing these complex blends is technically challenging. Thus, stimulus distribution in odor space (the frequency with which compounds and their combinations occur in nature) remains largely obscure. Here, we undertake the first large-scale survey of an odor space relevant to blood-feeding insects: vertebrate body odors. We confirm previous evidence that these odors are mostly composed of ubiquitous compounds; measuring any one compound provides minimal information about stimulus identity. Thus, blood feeders' sensory systems must be tuned not to single, host-specific compounds but to distinctive compound ratios in an odor of interest. We describe the major axes that separate vertebrate odor from other environmental odors and discuss candidate compounds that blood-feeding insects may use to target hosts. We also describe how vertebrate odor varies across species, including consistent differences between human and non-human odor that result from unique aspects of human skin biochemistry. Prior evidence suggests human-specialist mosquitoes indeed exploit these cues. By analyzing the structure of vertebrate odor space, our work generates predictions about how a sensory system should carve out a section of odor space to focus on relevant stimuli. These results may also inform the development of novel baits or repellents that can be used to manipulate the behavior of blood-feeding insects.

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P20-4 Abril, JT*; Gaviria, MA; Harper, JM; Sam Houston State University; *jmharper@shsu.edu*

Food availability alters stress resistance in speckled cockroaches (Nauphoeta cinerea)

Organisms are "forced" to allocate resources in a manner that should benefit their long-term reproductive success, but the devotion of resources to one process comes at the expense of other processes. Here, we manipulated food availability for populations of speckled cockroaches (*Nauphoeta cinerea*) to study the effect on body mass and stress resistance using a simple feeding regimen. In short, individual cockroaches had access to either: (1) unlimited food (puppy chow; ad libitum or AL) or (2) limited food availability via the manipulation of the number of feeding stations, as well as the provision of the diet itself. In one instance, individual cockroaches had access to puppy chow at each of two feeding stations that were refilled only when all chow had been consumed (2T). For the second feeding condition, food was provided at a single feeding station which was refilled when completely empty as above (1T). This feeding regimen had been maintained for approximately 300 days prior to the initiation of this study and all individuals would have been from the third generation continuously exposed to these conditions. Despite the most limited access to food, cockroaches in the 1T condition were significantly heavier than those in both the AL and 2T groups. Consistent with this difference in body mass, we also found that 1T individuals were more susceptible to both heat stress (45° C) and cadmium chloride ($CdCl_2$) induced toxicity using time until death as a metric. These results suggest that speckled cockroaches invest more resources toward growth when food is limited at the expense of cellular defense pathways. It remains to be seen whether the increased body mass is associated with increased fecundity as predicted.

P4-4 Aguilar, LK*; Collins, CE; Hammond, AS; American Museum of Natural History, New York City and Harvard University, Cambridge, MA, Sacramento State University, CA, American Museum of Natural History, New York City and New York Consortium of Evolutionary Primatology (NYCEP); *laguilar@g.harvard.edu*

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Predicting primate hip function based on bony morphology using path analysis
Acrobatic primates (e.g., apes, ateline monkeys) have been shown to have greater ranges of motion at the hip than primates using more stereotyped locomotion (e.g., cercopithecines), which should reflect different positional needs between these two locomotor groups. However, how bony morphologies of the femur and pelvis interact to produce differing hip function remains poorly modeled. In this study, we conducted theory-based path analyses via structural equation modeling to determine which bony morphologies are the strongest predictors of hip range of motion in acrobatic and stereotyped anthropoid primates. Seven femur morphologies and two hip range of motion measures were obtained from nine acrobatic species (n=99 individuals) and 13 stereotyped species (n=109 individuals). Through variable selection and fit testing techniques, insignificant predictors were removed to create the most parsimonious final models for each group. While some morphological predictors, such as femur shaft length and neck-shaft angle, were important across groups, different combinations of bony morphologies best predicted hip range of motion in each locomotor group, demonstrating specific morphology-mobility-behavior linkages. Our models elucidate biologically important relationships between morphology and performance, which will be used in future studies to estimate hip function in fossil primates.

P39-5 Aichelman, HE*; Benson, BE; Castillo, KD; Baumann, JH; Rippe, JP; Nieves, OC; Pereslete, AM; Stanizzi, DA; Tsang, LC; Davies, SW; Boston University, University of California, Davis, University of North Carolina, Chapel Hill, Bowdoin College, University of Texas, Austin; *hannahaichelman@gmail.com*
Diel thermal variation supports growth and symbiosis in a reef-building coral
Rising sea surface temperatures pose the greatest threat to corals and lead to bleaching. Coral bleaching predictions typically consider duration and magnitude of elevated temperatures relative to a locally defined thermal threshold. However, recent work suggests that heterogeneity in bleaching patterns may be better explained by degree of diel thermal variation (DTV). We sourced colonies of the reef-building coral *Siderastrea siderea* from six

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reefs across Bocas del Toro, Panama which ranged in mean DTV (~1-3° C). We conducted a 50-day common garden experiment to assess the influence of low, moderate, and high DTV (2, 3, and 4° C, respectively) and then performed a two-week thermal challenge (32° C) followed by a two-week recovery period. Metrics of coral host (growth, carbohydrate, protein, tissue thickness, corallite area) and symbiont (carbohydrate, chlorophyll, density, and mitotic index) physiology were assessed to disentangle how natal reef DTV modulates a coral's response to DTV, thermal stress, and recovery. Results suggest that corals sourced from higher DTV sites outperformed corals from less variable sites, regardless of treatment. High experimental DTV increased growth and corals that experienced moderate DTV maintained higher symbiont densities after recovery. Analyses are ongoing; however, results will shed light on how DTV modulates a coral's response to temperature stress and recovery. Our data support the hypothesis that DTV *in situ* and in husbandry plays a central role in growth and symbiosis of reef-building corals, highlighting the need to consider DTV when evaluating the resilience of corals to global change.

P21-1 Akinrinade, AO*; Jensen, JS; University of Washington, Bothell; *ayoaki@uw.edu*

Relationship between diet and gill raker morphology in Surfperches (Embiotocidae)

Numerous studies have shown the importance of gill raker variation in trophic ecology. The North Pacific fish family Embiotocidae (surfperches) show remarkable dietary diversity despite being composed of only 23 species. The family includes feeding specialists and generalists, substrate feeders and open water feeders, and species that feed on immobile hard-shelled prey and species that feed on highly mobile prey. Much attention has been given to their oral jaws and their well-developed pharyngeal jaws, but little attention has been given to variation in their gill rakers. In this study, we compare gill raker morphology, number, and length across the full phylogenetic and ecological range of this family. The phylogeny of surf perches is well understood, allowing us to map the evolution of gill raker variation and draw associations between gill raker variation, historical constraint, and ecological shifts. For example, within each of the subfamilies,

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planktivory is associated with more gill rakers related to substrate feeding. Given their ecological range, well-described phylogeny, and tractable species number, surfperches are a model system for investigating the evolution of gill rakers in perciform fishes.

P39-10 Akther, T; Easson, CG; Collin, R; Thacker, RW*; Stony Brook University, Middle Tennessee State University, Smithsonian Tropical Research Institute, Stony Brook University and Smithsonian Tropical Research Institute; *robert.thacker@stonybrook.edu*

Comparing adult and larval microbiomes in the tropical sponges Neopetrosia sigmafera and Xestospongia bocatorensis

Marine sponges host distinct communities of symbiotic microbes that can be acquired through both horizontal (from the environment) and vertical (from the parents) transmission. Two common species of sponges from Bocas del Toro, Panama, *Neopetrosia sigmafera* and *Xestospongia bocatorensis*, brood their developing embryos within the adult sponge. We tested the hypothesis that larval microbiomes are vertically transmitted from parents to offspring by capturing larvae released from adults of each of these two species in aquaria. We extracted metagenomic DNA from adults, larvae, and the surrounding seawater. We followed the protocols of the Earth Microbiome Project to amplify the V4 region of the 16s ribosomal RNA subunit, and sequenced the resulting amplicons on an Illumina MiSeq platform. We analyzed the resulting sequences using the mothur and DADA2 bioinformatics pipelines. We used the R package "vegan" to analyze differences in the relative abundances of bacteria between the two sponge hosts (including their adult and larval life stages) and the ambient seawater. These two sponge species host microbiomes that are significantly distinct from each other and the surrounding seawater. For *N. sigmafera*, a large diversity of symbiotic microbes was observed in the adults, but a subset of this diversity was hosted by larvae. For *Xestospongia bocatorensis*, a low diversity of microbes was hosted by both adults and larvae. Microbiome community structure was significantly different between adults and larvae of *N. sigmafera*, but not between adults and larvae of *X. bocatorensis*. These results suggest that microbiome composition might influence the differences in larval duration observed between these two species.

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P37-3 Albers, JM*; Reichert, M; Oklahoma State University; *jonathan.m.albers@okstate.edu*

The effects of aggression and neophobia on olfactory learning in crickets

Personality traits such as exploratory behavior and boldness have been shown to influence the cognitive performance of animals. Aggression has not been looked at as much, despite evidence showing that cognition influences aggression in animal contests. This study looks at the relationship between aggression, neophobia, and learning in the cricket ""*Acheta domesticus*. We characterized individual variation in aggressiveness by monitoring the intensity of agonistic behaviors exhibited by each individual in a series of contests. Neophobia was tested with a novel object test. The crickets were then placed in a maze that tested their ability to learn using their olfactory senses and reverse learn various odors associated with a reward and a punishment. We expect to find that more aggressive and neophilic individuals will learn the initial association faster but will perform worse on the reversal than less aggressive and neophobic individuals. This research will help look at how individual variation interacts with learning and aggression and will help provide more information on how personality traits affect learning.

P7-7 Alexander, JRS*; Hagood, ME; Porter, ME; Florida Atlantic University; *josephalexan2019@fau.edu*

Sex-specific variation in the structure and mechanical properties of shark skin

Elasmobranch (sharks, skates, and rays) skin is a biological network composed of dermal denticles and underlying collagen fibers. Elasmobranch fishes have variable skin thickness, where female skin is up to 50% thicker and has larger angles in the collagen network than males. The increased thickness protects females from injury during mating behaviors and larger ventral collagen fiber angles accommodate body expansion and deformation during feeding and pregnancy. We evaluated anisotropic tensile mechanical properties of silky shark (Carcharhinus falciformis) skin taking into account sex, testing orientation (hoop or

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longitudinal), dermal denticle density, and collagen fiber angle as effects. We predicted that mechanical properties would be greater in skin from females, and that denticle density and collagen fiber angle would increase with mechanical properties. We dissected skin from sharks from between the two dorsal fins, including the dorsal and ventral surfaces. We cut each piece of skin into a grid of 5x5cm squares of skin, and each square was photographed with a Leica stereoscopic microscope to quantify collagen fiber angle and dermal denticle density. Skin was tested using an Instron E1000 to examine anisotropic mechanical data at 2 mms-1 strain rate. We found that max load (N) and load at fracture (N) were significantly greater in female silky shark skin compared to males. We found that shark skin tested the hoop orientation had greater max loads (N), stiffness (MPa), and ultimate strength compared to the longitudinal direction. Finally, we found that dermal denticle density increased significantly as max load (N), strength (MPa), and toughness (MPa) decreased. This study adds to our understanding of the impacts of skin morphology on function.

P13-9 Allen, CB*; Root, ZD; Medeiros, D; University of Colorado Boulder; *caal0667@colorado.edu*

Investigating the functions of hyaluronan and chitin and their evolutionary importance across vertebrates

The extracellular matrix (ECM) is a dynamic system whose innovations have helped facilitate morphological evolution in animals. ECM components provide structure and support and also direct tissue differentiation and cellular communication. An ECM component of interest in vertebrates is hyaluronan (HA), a glycosaminoglycan (GAG) that aids in the development of the heart, brain, and jaw. Likewise, of interest in invertebrates is chitin, which is involved in the formation of the exoskeleton and digestive tract. Despite HA and chitin's different functions, they are thought to be duplicates of a common ancestral glycosyltransferase gene. Previous studies have identified three HA synthase (Has) genes unique to vertebrates. Several vertebrates maintain both HA and chitin. This led to the question of how HA and chitin play a role in the development of the vertebrate body plan, by examining organisms that lack morphological structures most vertebrates share. We decided to look at Has genes in sea lamprey, *Petromyzon*

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marinus, a jawless vertebrate that diverged about 500 million years ago. *In situ* hybridization and histochemical staining led to the discovery of five Has genes in lamprey. The lamprey transcriptome revealed three type-II chitin synthase (Chs) genes. Has and Chs expression patterns in lamprey are comparable to that of other vertebrates, with few notable exceptions with Chs. We were next interested in the interplay between HA and chitin during development, doing loss-of-function experiments in *Xenopus laevis* for Has and Chs genes. Our findings suggest that ancestral gene duplication events in Has and Chs genes predate the divergence of vertebrate and invertebrate chordates. We also suggest that the evolution of the vertebrate body plan involved recruiting the novel GAG HA and the progressive loss of chitin.

P24-6 Alms, DM*; Langager, MM; Weitzman, CL; Hawley, DM; Virginia Tech; *dma080@vt.edu*

The effect of Mycoplasma gallisepticum infection on feather quality and maintenance in house finches (Haemorhous mexicanus)

When organisms, such as songbirds, are faced with an active pathogen infection, there can be pronounced energetic tradeoffs. These tradeoffs may affect several systems within an organism, including behavioral maintenance of external structures. In songbirds, behavioral feather maintenance (preening) is critically important to their survival and fitness. *Mycoplasma gallisepticum* (MG) is a common pathogen of house finches, a songbird species, where it causes the disease mycoplasmal conjunctivitis. To date, no studies have examined how preening behavior changes with MG infection and how these differences in preening may affect feather quality. To test this, 32 wild-caught, captive house finches were given one of three treatments: a high (10^4) dose of MG (n=11), a mid (10^3) dose of MG (n=11), or a sham control treatment of sterile media (n=10). Behavioral videos were recorded both during pre-infection and at peak-infection to determine the proportion of time spent preening and time spent inactive. One month post-inoculation, a secondary flight feather was clipped and examined under a microscope to score the amount of feather degradation on a 1-4 scale. We found that birds infected with MG, regardless of dose, preened significantly less often and were significantly less active than sham controls. However, there

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were no differences in feather quality scores between control and infected individuals, which may partly be due to the controlled environment the birds experienced while in captivity. Our data suggests that infection strongly affects the behavior of house finches by decreasing their overall activity, including behaviors critical to survival such as preening.

P31-4 Alomar, N*; Farallo, V; Muñoz, M; Longo, A; Univ. of Florida, Univ. of Scranton, Yale Univ.; *nathalie.alomar@ufl.edu*

Microhabitats influence on the anti-fungal bacteria diversity of Plethodontid salamanders

Plethodontid salamanders are generally considered resistant to fungal pathogens due to their symbiotic relationships with skin bacteria. We hypothesized that microhabitat selection among salamander species can affect bacterial recruitment, leading to differences in microbial community and resistance against pathogens. In this study, we compared skin bacteria isolated from three closely related species with different microhabitat preferences: *Plethodon cinereus*, a habitat generalist, and two microendemic species, *Plethodon sherando* and *Plethodon hubrichti*. To do this, we swabbed the skin of the salamanders (N= 9 per species) and isolated distinct colonies of bacteria. We then sequenced the 16S ribosomal gene and identified bacteria to the highest taxonomic level possible. To test their inhibition ability, we challenged bacterial isolates against *Batrachochytrium dendrobatidis*, a widespread amphibian fungal pathogen. In addition, we collected publicly available microbiome datasets and investigated the occurrence and overlap of isolated bacteria with amplicon sequence variants detected via targeted sequencing. This information is expected to provide a broader context of the microbial diversity found in our focal species compared with other Plethodontid family members. Our results showed differences in bacterial composition where *P. cinereus* had the lowest diversity yet the highest number of antifungal bacteria. Our findings indicate these three salamanders encounter distinct bacterial species pools and that high diversity of bacteria does not necessarily correlate with a high richness of antifungal bacteria. Considering a species microhabitat can widen our perspective about

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how microbiome diversity of amphibians leads to a more equipped fight against fungal threats.

P15-8 Alonge, MM*; Greville, LJ; Ma, X; Faure, PA; Bentley, GE; University of California, Berkeley CA USA, McMaster University, Hamilton, Ontario, Canada, University of California, Berkeley CA uSA; *mattina.alonge@berkeley.edu*

Rapid effects of acute stress on reproductive neuroendocrinology and gonad function in the big brown bat (Eptesicus fuscus)

Unpredictable changes in environment sometimes require rapid flexibility in an animal's physiological response. Coordinated signaling regulates reproductive physiology via the hypothalamic-pituitary-gonadal (HPG) axis. Gonadotropin-inhibitory hormone (GnIH, mammalian ortholog RFRP-3) is known to inhibit the HPG in many vertebrates; however much remains unknown about its role and responsiveness to physiological challenges, especially in a comparative context. HPA activation and circulating glucocorticoids have been found to increase GnIH content in the brain and gonads of some species, and may suppress reproduction by action in both tissues. Reproductive neuroendocrinology is historically understudied in bats despite interesting annual reproductive life-history patterns of temperate species. Using wild-caught captive big brown bats (*E. fuscus*) we determined acute stress effects on hypothalamic neuropeptides and gonad function. Male bats were sacrificed immediately (n=8) or subjected to 60 min restraint (n=8) after which whole brains, testes, and blood were sampled. Stress induced a 6-fold increase in corticosterone and rapid decrease in plasma testosterone. RFRP-3, GnRH, and c-Fos cell immunoreactivity was quantified and relative gonadal steroidogenic mRNA expression determined alongside cellular apoptosis markers. Understanding how stress affects bat reproductive physiology will provide knowledge essential to making predictions about individual fitness and, broadly, success of populations in the face of dynamic environments.

P29-3 Anderson, KN*; Dotterweich, MM; Hardy, KM; California Polytechnic State University, SLO; *kande145@calpoly.edu*

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Does predator presence influence anaerobic metabolism and behavior in the acorn barnacle Balanus glandula?

The acorn barnacle, *Balanus glandula*, has been shown to exhibit tidal zone-dependent differences in anaerobic capacity and cirral behavior. Specifically, barnacles in the low intertidal had higher lactate dehydrogenase (LDH) activity and spent less time cirri beating while submerged than conspecifics from the high intertidal. We hypothesize that increased LDH activity in low intertidal *B. glandula* results from increased predator exposure, and thus more prolonged shell closure, during longer periods of immersion. To explore this, we measured the density of *B. glandula* and the predatory snail *Acanthinucella spirata* across tidal heights at several intertidal sites in California. And in the lab, we compared barnacle cirral activity in the presence and absence of A. spirata. We found the density of both barnacles and snails was significantly higher in the low intertidal relative to the high at all field sites. Further, 10% fewer barnacles were feeding during the first 1.5h of predator exposure, compared to unexposed barnacles, though this pattern disappeared by 24h. While more predators were found in the low intertidal, their effects on barnacle behavior were small and short-term, and therefore unlikely to alter LDH activity. This led us to question the universality of the tidal height effects on LDH and cirral beating in *B. glandula*. Unfortunately, we could not replicate the original relationship between tidal height and LDH activity at several novel intertidal sites. Barnacles from the high intertidal, however, still engaged in more cirral beating than those from the mid or low. The effects of tidal position on anaerobic metabolism in B. glandula may not be as pronounced as originally thought, though feeding behavior is still linked to tidal height.

P17-5 Apulu, NJ; University of Arkansas; *napulu@uark.edu*

Investigating the mechanism by which the class IV POU transcription factor regulates the maturation of distinct mechanoreceptor cell types in Cnidaria

The class IV POU homeodomain transcription factor (POU-IV or Brn3) controls the differentiation of distinct neural cell types in Bilateria and its sister group Cnidaria, indicative of an evolutionarily ancient role for POU-IV in neural differentiation.

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In the cnidarian Nematostella vectensis, we and others have found that POU-IV regulates the maturation of mechanosensory cell types, namely, hair cells and stinging cells known as cnidocytes. However, the mechanism by which POU-IV orchestrates the maturation of two distinct mechanosensory cell types is not known. To bridge this knowledge gap, we are studying the identity and function of downstream target genes of POU-IV. By using ChIP-Seq and RNA-seq, we find that a number of effector genes such as ion channel-encoding genes are directly activated by POU-IV, while several transcription factor-encoding genes, including a cnidocyte differentiation gene PaxA, are directly repressed by POU-IV. Regarding which downstream target genes of POU-IV are involved in the maturation of hair cells, cnidocytes, or both are currently being investigated.

P13-6 Arnaoudoff, LA*; Sanger, TS; Loyola University Chicago, Illinois; *larnaoudoff@luc.edu*

A three-dimensional interactive embryological atlas of Anolis sagrei based on micro-CT

With the rapid rise of Evo-devo and the concurrent development of new imaging techniques, comparative studies of development have accelerated over the last decade. Squamates, lizards and snakes, lack a traditional experimental model species for developmental investigations, yet are important for understanding fundamental evolutionary questions because of their remarkable diversity. However, several squamate species have growing communities of biologists building new resources for comparative and experimental studies of lizard development. Creation of detailed embryological atlases for these species will help promote their advancement. In the past, scientists have had to rely on destructive methods to conduct detailed studies of internal anatomy. However, X-ray computed tomography, CT scanning, allows for sub-10 micron, non-destructive imaging of vertebrate embryos. This technique allows not only the ability to analyze the hard tissues, but also, with the help of chemical counterstains, the ability to differentiate soft tissues. We have created a detailed, 3D embryological atlas of the model lizard species, Anolis sagrei, using micro-CT scanning. We are reconstructing the development of both hard and soft tissues, such as bone, muscle, and neural tissues. All

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reconstructions are being conducted in the free software package 3D Slicer. 2D slices can be used for virtual histology of each stage. 3D models are posted on Sketchfab, a platform that allows viewers to move, resize, and interact with 3D models on a web-based interface. This anatomical atlas will be essential resource for research on Anolis development, as well as educational purposes, and will help create a more comprehensive understanding of the embryonic development of anoles.

P6-4 Artime, LE*; Wilcoxen, TE; Millikin University, Millikin University ; *lartime@millikin.edu*

Association of cap plumage color, cap size, and physiological traits in White-breasted Nuthatches (Sitta carolinensis)

Carotenoid- and melanin-based coloration have been indicated as biomarkers of individual quality and as traits associated with sexual selection in many bird species. Though not mutually exclusive, coloration of birds may also contribute to camouflage, signaling of species identity or social membership, temperature regulation, or in anti-predator defense. Within these different aspects of avian coloration, there is often significant variation among members of the same species; thus, the coloration of a bird may be an honest indicator of physiological condition. We assessed relationships between melanin-based plumage coloration and physiological profiles in the white-breasted nuthatch (*Sitta carolinensis*). Throughout most of the species' range, male white-breasted nuthatches have dark black caps, while females and recently-fledged hatch year birds have lighter gray caps. We captured white-breasted nuthatches from June to September 2020, quantified cap color, cap size relative to head size, and analyzed blood samples for leukocyte counts, parasite loads, testosterone levels, and antioxidant capacity. While the diversity in cap color and size differs between sexes, we found considerable variation in cap color and size within groups of male and female nuthatches. Our findings may reveal underlying mechanisms in expression of the melanin-based cap coloration in this species.

P41-1 Ashlyn, A*; Daley, MA; Hubicki, CM; FAMU-FSU College of

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Soft-ground gait dynamics and transitions in avian running

Bipeds regularly encounter soft surfaces with changing properties when running in the natural world. However, most bipedal running experiments are conducted on treadmills or hard terrain. This study addresses the effects of soft terrain on unsteady overground bipedal running. Experiments were set up where guinea fowls ran down a hard-ground runway with a soft terrain patch in the middle to test our hypothesis that terrains of varying stiffness and damping properties will yield differing gait dynamics and neuromechanical control priorities in locomotion. Four different types of terrain were used: memory foam, stiff foam, sand, and level ground for a control. Preliminary results showed differences in the average vertical forces, fore-aft forces, and fore-aft impulses calculated for each terrain type. The most apparent difference was an extra peak in the average fore-aft force. K-means clustering showed groups of forces existed independent of terrain type and individual. Further analysis is being conducted to determine if the preliminary differences in clusters and force trajectories are related to terrain type.

P10-1 Assar, S*; Durhman, M; Townsend, KEB; Echols, MS; Midwestern University, Glendale, AZ, Scarlet Imaging, Salt Lake City, UT; *btowns@midwestern.edu*

Anatomy of the hyoid musculature in the snow leopard (Panthera uncia)

The snow leopard (*Panthera uncia*) is currently considered vulnerable by the IUCN, with approximately 5,000 individuals left in the wild with a 20% decline in their population in the last two decades. The hyoid apparatus of this felid has been documented, but the musculature of this region has not. The hyoid region of snow leopards is of interest because they have an incompletely ossified hyoid apparatus and they produce distinctive vocalizations among the Felidae. Similar to other pantherines, the snow leopard can elongate the vocal tract by moving the larynx away from the oral cavity to produce lower-pitched sounds. In this study, we dissected, documented in detail, and imaged the hyoid apparatus and musculature in two adult *P. uncia* specimens (1M/1F). Our results indicate that the occipitohyoideus, found in numerous carnivorans

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and felids, is not present in the snow leopard, instead it may be fused with the stylohyoideus. In lions, the sternohyoideus and sternothyroideus both take origin from the second sternebra, however in *P. uncia*, these muscles take origin from the second sternebra and the first and second rib. The omohyoideus is absent in the snow leopard, not unlike the condition seen in other feliformes. The geniohyoideus is not fused in the midline, which is similar to the condition seen in the tiger. The stylohyoideus inserts on the stylohyoideum via a fascial band, similar to the tiger and the serval. Our initial results suggest that the hyoid musculature of the snow leopard displays unique features, which may shed light on its distinctive vocalizations.

P27-6 Assis, VR*; Titon, SCM; Titon Jr, B; Gomes, FR; University of Sao Paulo; *v.regina.a@gmail.com*

Corticosterone transdermal application impact on toads (Rhinella icterica) phagocytosis

Recent studies show acute stress-induced immunomodulation, particularly emphasizing that physiological increases in endogenous glucocorticoid levels have immunostimulatory effects. Although immunosuppressive effects have also been described, the difference between enhancing or suppressing the immune response seems to be mediated by the duration and intensity of the stressor, and the immune component analyzed. We aimed to understand how acute increased glucocorticoid levels of different intensities, promoted by two corticosterone (CORT) doses (1 and 10ug) using the transdermal application (TA), affect CORT and testosterone (T) plasma levels and immune parameters (plasma bacterial killing ability (BKA), and phagocytosis of peritoneal leukocytes (PP)] in toads (*Rhinella icterica*). Toads were bled one hour after TA (CORT or vehicle), and subsequently received an intraperitoneal injection of zymosan-CFSE. One hour following the zymosan-CFSE injection, toads were euthanized to collect the peritoneal lavage fluid. CORT TA increased plasma CORT levels with different intensities: three times for 1ug and fourteen times for 10ug, although there was no effect of any dose on T levels and BKA. Interestingly, both CORT doses promoted immunosuppression, decreasing phagocytosis in 60% for toads receiving the dose of 1ug and 40% for those receiving 10ug. Thus, CORT immunomodulatory effect on amphibians appears to

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be quite complex, and not just dependent on the intensity of CORT increase. Moreover, the immunomodulatory effect varied according to the immune component analyzed (complement proteins *vs.* cellular response).

P19-5 Audino, JAA*; Serb, JM; Marian, JEA; Iowa State University, Department of Ecology, Evolution and Organismal Biology, Iowa, USA, University of São Paulo, Department of Zoology, São Paulo, Brazil; *audino@iastate.edu*

Untangling the diversity and evolution of tentacles in scallops, oysters, and their relatives (Bivalvia: Pteriomorphia)

Tentacles are multifaceted organs found in many aquatic invertebrate groups. In bivalves, tentacles are diverse, performing protective and sensory roles in numerous taxa with different ecologies. Such diversity is particularly accentuated in Pteriomorphia, a clade comprising scallops, oysters, file clams, and relatives. However, little is known about the evolution of these organs and their role in bivalve radiation. To test hypotheses of convergent tentacular evolution and possible association between tentacles and body orientation on the substrate, we first examined tentacle morphology in 108 preserved species representing 15 families across Pteriomorphia. Morphological descriptions of tentacle type (inner mantle fold tentacles - IFT; middle mantle fold tentacles - MFT) and position (marginal and submarginal) are provided, expanding the knowledge of less studied bivalve taxa. Then, we placed the morphological dataset under a molecular phylogenetic framework to estimate ancestral states. IFT likely had four independent origins, while MFT emerged twice independently. After being gained, tentacles have not been lost. In addition, evolution of MFT coincides with transitions in body position with the midsagittal plane parallel to the substrate in the clades of scallops (Pectinida) and oysters (Ostreida). Such a shift could be related to the increase of mantle exposure, favoring the emergence of serially repeated organs, such as tentacles. Altogether, our results support the convergent evolution of tentacles across different taxonomic levels, contributing to elucidate the diversification of bivalve anatomy.

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P20-5 Badwan, S*; Harper, JM; Sam Houston State University; *jmharper@shsu.edu*

Size matters: body size is correlated with longevity in speckled cockroaches (nauphoeta cinerea)

A relationship between body size and longevity has long been appreciated within eukaryotes, especially vertebrates. For example, large size (typically body mass) is associated with increased longevity among species of mammals, but within individual species such as dogs and mice larger individuals tend to die sooner. However, whether or not there is a relationship between body size and longevity has not been well-investigated in invertebrates with the exception of mutant strains of Drosophila melanogaster in that mutant strains with a small body size being longer-lived than normal sized control strains. In this study, we examined the relationship between measures of body size and longevity in a captive population of speckled cockroaches (*Nauphoeta cineria*) and found that, contrary to what has previously been reported, larger cockroaches were significantly longer-lived than their smaller counterparts. Body mass, body length and pronotum width at the time of death were all significantly correlated with the age at death in a mixed population of males and females (n = 94). In addition, we found that the longevity of a historically larger population in terms of body mass and body length was also significantly greater than the test population used in this study. Taken together, these data suggest that there is a significant interaction between body size and aging in this species due to an unknown mechanism, but insulin-insulin-like growth factor signaling (IIS) has strongly been implicated in other models.

P21-8 Bagana, M; Danos, N*; University of San Diego, University of San Diego ; *mbagana@sandiego.edu*

Sexual dimorphism in chameleon feeding

BAGANA, M; DANOS, N; University of San Diego; mbagana@sandiego.edu **Sexual dimorphism in chameleon feeding.** Sexual dimorphism of skull anatomy is prevalent among chameleons. Male Jackson's chameleon, *Trioceros jacksonii*, have three cranial bony horns. However, these horns are not present in females. Given the highly specialized feeding mode of chameleons, we wanted to know whether this large cranial skeletal feature incurred a cost on male

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feeding performance. We filmed 14 male and 16 female animals at 250 frames per second from ventral and lateral views as they fed on a stationary held cricket, and quantified three-dimensional tongue kinematics. We found no sexual dimorphism in tongue projection kinematics, suggesting that there is little or no fitness cost associated with the large horns of the male *T. jacksonii*. Preliminary data from *Chamaeleo calyptratus* had suggested that females have a relatively larger entoglossal process of the hyoid. However, this did not hold true for a much larger sample of *T. jacksonii* (N=59 and N=103 for females and males, respectively). In fact, we found no evidence of sexual dimorphism in cranial morphology other than the presence or absence of horns. The absence of sexual dimorphism is highly unusual for chameleons. We explored whether there were changes in the ecology of the species from high altitudes in East Africa to lower altitudes after their introduction to Hawaii.

P12-4 Baker, SA*; Lewis, PJ; Sam Houston State Univeristy; *sab030@shsu.edu*

The quantitative analysis of coronal suture separation due to cranial trauma

Morphometric analysis of cranial sutures can provide evidence of microfractures, diastasis, and early sutural closure. Recently, mCT has allowed for morphometric analyses on much smaller scales and has been used to differentiate normal cranial sutures from early sutural synostosis. Results suggest that more data may be available at microscopic levels. Here, I tested for asymmetrical separation in coronal sutures to determine if significant differences could be detected by comparing the sides that received trauma with the contralateral regions. Three human cranial trauma cases and one control specimen from the Southeast Texas Applied Forensic Science Facility in Huntsville, TX were used in this study. All specimens were European adult males >56 years of age. Trauma cases included: 1) an intraoral gunshot wound; 2) blunt force trauma; and 3) sharp force trauma. Amira 6.7.0 was used to calculate the maximum distance of separation of the suture and total area of separation for individual scan slices. Asymmetry was determined by comparing the differences in coronal suture separation between the left and right sides delineated by intersection with the sagittal suture

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(bregma). To standardize data collection, imaging of the coronal sutures began at their origin (pterion) and terminated at bregma. Equal numbers of scan slices were selected and measured between landmarks at ~10mm intervals. Maximum sutural width was measured as the largest distance observed, and total open area was calculated. Paired t-tests were used to assess statistical significance in both quantitative measures for each specimen. Preliminarily results suggest asymmetry in both variables. Ultimately, these data could provide forensic scientists another method to assess injury and may lead to a more thorough understanding of sutural diastasis in adult human skulls.

P13-11 Baldwin, SC*; Benton, JL; Beltz, BS; Wellesley College, Department of Neuroscience, Wellesley, MA; *sbaldwi3@wellesley.edu*
Effects of astakine and serotonin on adult neurogenesis
Neurogenesis, the generation and integration of neurons into brain circuits, occurs throughout the lives of numerous organisms, ranging from mammals to crustaceans. Unlike mammals, the first-generation precursor cells in crayfish, which are housed in a neurogenic niche, are not self-renewing but rather are replenished by the immune system. Previous studies have shown that hemocytes (blood cells) are attracted to the niche and can differentiate into neurons. To better understand the link between the immune and the nervous systems, the influences of the neurotransmitter serotonin and the cytokine astakine on neurogenesis were tested. 1) Increased levels of 5-HT result in an attraction of hemocytes to the neurogenic niche, and also stimulates the expression of astakine in hemocytes. 2) Astakine then encourages the release of semi-granular cells, a particular type of hemocyte thought to be responsible for renewing the niche precursor cells. 3) Adoptive transfer experiments have shown that labeled hemocytes transferred from donor to recipient crayfish are found in recipient neurogenic niches and generate offspring that express appropriate neurotransmitters. 4) Further, exposure of recipient crayfish to increased serotonin levels increases the incorporation of donor hemocytes into recipient niches. With this knowledge, we designed an experiment to test whether serotonin and astakine serve as links between the immune and nervous systems. In adoptive transfer experiments, hemocyte donors are treated with astakine to provide

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maximal numbers of labeled hemocytes for transfer to recipient crayfish, and recipients are treated with serotonin. We hypothesize that these treatments will result in higher hemocyte counts in donor crayfish and more cells in the neurogenic niche compared to controls.

P10-7 Bart, H; Greenberg, J; Karpatne, A; Mabee, P; Maga, AM*; Tulane , Drexel, Virginia Tech, Battelle, Seattle Children's Research Institute; *maga@uw.edu*

Biology-guided neural networks (BGNN) for discovering phenotypic traits

Unlike genetic data, the phenotypes, or traits of organisms such as their visible features, are not available in databases for analysis. The lack of machine-readable trait data has slowed progress on four grand challenge problems in biology: predicting the genes that generate traits, understanding the patterns of evolution, predicting the effects of ecological change, and species identification. The BGNN project aims to leverage advances in state-of-the-art machine learning to develop a novel class of artificial neural networks, termed biology-guided neural networks (BGNNs), that can exploit the machine readable and predictive knowledge about biology that is available in the form of phylogenies and anatomy ontologies. These BGNNs are expected to automatically detect and predict traits from specimen images, with little training data. Currently the project is focusing on teleost fishes because of many high-quality data resources available (digital images, evolutionary trees, anatomy ontology). The resulting machine learning model can be generalized to other disciplines that have formally structured knowledge, and will contribute to advances in computer science by going beyond black-box learning and making important advances toward Explainable Artificial Intelligence. Image-based trait data derived from this work will enable progress in gene-phenotype mapping to novel traits and understanding patterns of evolution. It may be extended to applied areas, such as agriculture or the biomedical domain. This convergent research will accelerate scientific discovery across the biological sciences and computer science by harnessing the data revolution in conjunction with biological knowledge.

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P18-3 Barts, N*; Toner, C; Meyer, W; Kohl, K; University of Pittsburgh, Lehigh University ; *nickrbarts@gmail.com*

A case of convergence: evolution of a digestive lysozyme in herbivorous rodents

Charles Darwin famously suggested that organisms can evolve nearly endless forms, however, biologists frequently identify the emergence of similar phenotypes in independent lineages experiencing similar selective pressures. Indeed, convergent evolution is pervasive in nature and evidence of convergence can be found across levels of biological organization. Foregut fermenting herbivores represent a classic example of convergent evolution. Colobine monkeys and ruminants have evolved similar foregut chambers that house microbial communities capable of fermenting the plant materials that make up their diets. Additionally, these species have convergently evolved a unique lysozyme expressed in the acidic compartment of their digestive tract that assists in the digestion of microbes coming from the foregut. This enzyme has convergently evolved similar protein structure and exhibits a functional optimal at low pH. Interestingly, herbivorous woodrats (*Neotoma* spp.) exhibit similar digestive morphologies, host dense and active foregut microbial communities, and express a foregut lysozyme. Here, we hypothesized that convergence in digestive morphologies may have resulted in the convergent evolution of lysozyme structure and function. We tested for evidence of molecular evolution using the PAML package. Additionally, we found that the foregut lysozyme of herbivorous woodrats exhibited a more acidic pH optima when compared to house mice, similar to the adaptations of foregut fermenting primates and ruminants. Overall, our results provide an additional example of how the evolution of similar diets and digestive strategies shape patterns of convergence across distantly related taxa.

P38-10 Batts, E*; Whitman, K; Meissnner, K; Kevin, KM; University of Alabama, German Center for Marine Biodiversity Research; *aebatts@crimson.ua.edu*

Phylogenetic analysis of Icelandic Euphrosinidae utilizing DNA barcoding

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While molecular studies of annelid diversity and phylogeny have increased, many groups including the family Euphrosinidae (Amphinomida) remain understudied. Euphrosinids are generally small, short but stout annelids characterized by long, calcareous chaetae that are often distally forked or ringent. We examined 59 specimens of Euphrosinids from the 2011 and 2013 IceAGE (Icelandic Animals: Genetics and Ecology) cruises using light and scanning electron microscopy and sequenced fragments of the nuclear 28S rDNA and mitochondrial 16S rDNA genes. Three additional specimens from the Southern Ocean, one specimen off the coast of Southern California, and existing DNA 28S and 16S sequences were also sampled. Morphological studies revealed 5 morphospecies representing the three largest genera of Euphrosinidae to be present around Iceland. In our maximum likelihood analysis of 28S + 16S, *Euphrosine* was recovered as a 'basal' paraphyletic grade; a clade containing *E. aurantiaca* and *E. foliosa* (plus three unidentified species) was recovered sister to *Euphrosinopsis* + *Euphrosinella*. ABGD species delimitation analysis based on 16S sequences identified fourteen species with eight sampled from Icelandic or surrounding waters of which only two had existing sequence data. We have strong evidence for new species of *Euphrosinopsis* and *Euphrosinella*. Unfortunately, because most of this material was preserved in ethanol, we were unable to characterize key characters related to the branchiae needed for adequate species descriptions. DNA barcodes and images for all specimen are available on the Barcode of Life Data Systems database to assist in future studies on Euphrosinidae biodiversity.

P15-5 Beattie, UK*; Ysrael, MC; Romero, LM; Tufts University, Medford, MA; *ursula.beattie@tufts.edu*

Carbohydrate breakdown reflects wear-and-tear during a combined fast and chronic stress in house sparrows (Passer domesticus)

One aspect of the Reactive Scope Model is wear-and-tear, which describes a decrease in an animals' ability to cope with a stressor, typically because of a period of chronic or repeated stressors. With prolonged fasting, animals exhibit 3 phases of macromolecule breakdown for energy: phase I is primarily carbohydrate breakdown, phase II is primarily fat breakdown, and phase III is primarily protein breakdown. We investigated whether

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wear-and-tear due to chronic stress would accelerate a transition from phase II to phase III. We exposed house sparrows (*Passer domesticus*) to 3 weeks of daily fasts combined with intermittent repeated acute stressors to create chronic stress, followed by 2 weeks of daily fasts without stressors. In both a fed and fasted state, we used human point-of-care devices to measure glucose, β-hydroxybutyrate, and uric acid, which are indicative of carbohydrate, fat, and protein breakdown, respectively. We expected birds to be in phase II in a fasted state, but if wear-and-tear accumulated sufficiently, we hypothesized a shift to phase III. The birds did not exhibit a clear shift to phase III, however there was a pattern in carbohydrate breakdown that did not align with the hypothesis. In both a fasted and fed state, the birds increased carbohydrate breakdown throughout the experiment, suggesting wear-and-tear occurred, but was not sufficient to induce a shift to phase III. The birds also exhibited a significant decrease in weight, no change in corticosterone, and a transient decrease in neophobia with chronic stress. In conclusion, the birds appear to have experienced wear-and-tear, but our protocol was not sufficient to accelerate a transition to premature protein breakdown.

P18-1 Beech, ARF*; Berejka , BW; Smith, EB; Liu, Y; Tsunekage, T; Levin, II; Kenyon College, Agnes Scott College; *beech1@kenyon.edu*
Effect of lay order and breeding site on eggshell maculation and egg size in barn swallows (Hirundo rustica erythrogaster)
Eggshell maculation patterns have been studied extensively, leading to multiple adaptive explanations for the diversity in avian maculation pattern and egg size. This variation has often been attributed to signaling properties of eggshell patterns or habitat ecology (e.g., camouflage); however, our understanding of this variation is still somewhat limited. Our aim was to better understand the sources of intra- and inter-clutch variation in barn swallow (*Hirundo rustica erythrogaster*) egg size and maculation. We focused on two potential sources of variation within and between clutches: lay order as a source of intra-clutch variation in egg size and eggshell maculation, and breeding site, where we studied swallows breeding at organic, no-spray farms and near conventional agriculture. We photographed eggs (n=666) at multiple breeding colonies in two geographic locations (Georgia, Ohio). A subset of

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eggs (n=67) were labeled as they were laid to account for lay order. We predicted that the last-laid egg would look the most distinct from others in the clutch and that females breeding at no-spray farms would lay larger eggs. NaturePatternMatch was used to analyze the recognizability of patterns and calculate pattern similarity among eggs, and SpotEgg gave information including egg size, shape, number of spots, and spot distribution. Eggs typically resembled other eggs in the same nest more than eggs laid by other females. Additionally, the last laid egg in a clutch was consistently different in maculation compared to the earlier laid eggs. Breeding site influenced egg size such that females laid larger eggs at no-spray, organic farms.

P13-10 Bennett, CE*; Braasch, I; Michigan State University; *benne552@msu.edu*

Functional analysis of endothelin ligand genes in the development of the zebrafish neural crest cell population

Neural crest cells (NCC) are an embryonic cell population that differentiates into many tissues including e.g. heart, pigment cells, neurons, and craniofacial skeleton. Unique to the vertebrates like fish and humans, the neural crest forms along the dorsal neural tube before migrating throughout the embryonic body. The endothelin (Edn) signaling system is a key molecular regulator in cell fate determination, migration, and differentiation into different NCC derivatives. Endothelin peptide ligands and their respective G-protein coupled receptors make up the bona fide endothelin system, which newly evolved in a vertebrate ancestor. Vertebrate whole genome duplication events have then led to varying sets of Edn ligand and receptor genes among vertebrate lineages. Here, our objective is to better understand the developmental role of the five Edn ligands in the teleost fish zebrafish, *Danio rerio* following a teleost-specific whole genome duplication. Currently, the functional spectrum of most Edn ligands remains unknown. We used CRISPR-Cas9 genome editing to successfully knock out *edn2a, edn2b, edn3a, edn3b,* and *edn4* genes and combine them in a zebrafish endothelin quintuple mutant line. Interestingly, we have not yet detected any observable phenotypes in this mutant line beyond the known *edn3a/end3b* double mutant pigmentary defects, suggesting that the endothelin system acts in a highly redundant

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manner. The findings of this study enhance our understanding of the functions of the endothelin ligand gene family and provide insight into the evolutionary fates of paralogous genes following whole genome duplication.

P1-2 Bentley, VL*; Mykles, DL; Department of Biology, Colorado State University, Fort Collins, CO; *Vanessa.Bentley@colostate.edu*

The Crustacean juvenile hormone: Characterization of the methyl farnesoate signaling genes in the Gecarcinus lateralis Y-organ transcriptome

The antagonistic interaction between 20-hydroxyecdysone and juvenile hormone (JH) control insect molting and development, respectively. Methyl farnesoate (MF), the precursor to the insect JH-III, stimulates ecdysteroidogenesis *in vitro* in the Dungeness crab (*Metacarcinus magister*) Y-organ (YO). Components of the JH synthetic pathway, including farnesoic acid O-methyltransferase (FAMeT), are expressed in the blackback land crab (*G. lateralis*) YO, suggesting that the YO secretes MF. The components of the MF/MEKRE93 signaling pathway were identified using the *G. lateralis de novo* assembled multiple leg autotomy (MLA) and eyestalk ablation (ESA) transcriptomes, including Methoprene-tolerant (Met), Steroid receptor coactivator (Src), Krüppel homolog 1 (Kr-h1a and Kr-h1b), E93, and Hsp90. It is hypothesized that Kr-h1 mediates the control of ecdysteroidogenesis by MF. Kr-1a was differentially expressed over the molt cycle in MLA individuals and its relative expression by ESA was not mediated by mTOR activity. Kr-h1b was expressed at low levels and not affected by MLA or ESA. RNAi and *in vitro* experiments will determine the effects of methoprene and MF on YO ecdysteroid secretion and the effects of molt induction on the expression of MF/MEKRE93 pathway genes. Supported by NSF (IOS-1922701).

P7-11 Bhat, A*; Madhav, M; Jayakumar, R; Cowan, N; Fortune, E; Carnegie Mellon University, Johns Hopkins University, New Jersey Institute of Technology; *agbhat@andrew.cmu.edu*

Efficient localization of weakly electric fish with an electrode array

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Tracking the movement and electrical behavior of weakly electric fish offers insight into the interplay of sensing and social dynamics in the wild, along with an understanding of broader changes in the fishes' habitats. Localizing these fish using their electrical signals is challenging due to the nonlinear mapping between a fish's pose and the voltage it generates at any point in space, as well as signal interference among groups of fish. We present an algorithm to prune the space of possible fish locations given measurements from an electrode array, approximating the fish as a planar oscillating dipole. The algorithm relies on interpolation of the potential field and its gradient between neighboring electrodes. We then use this algorithm to initialize probabilistic trackers--a particle filter and an extended Kalman filter--and show that under conditions where the dipole model holds, the algorithm allows us to track the fish more efficiently than if we assume no prior knowledge of the fish's pose. We expect that when combined with probabilistic data association methods, our method will be useful in associating signals to fish during periods of interference. We also hypothesize that our method could be used for exact localization, given an interpolator that reflects the electric field characteristics of a planar dipole. Exploring data association methods and novel interpolation schemes will be the next step in our research.

P17-7 Bigasin, AR*; Goodheart, JA; Lyons, DC; University of California, San Diego; *abigasin@ucsd.edu*

Thirty-five genes found upregulated in Berghia stephanieae distal cerata

Nematocysts are specialized stinging organelles made only by cnidarians to fend off predators or catch prey. However, multiple metazoan phyla that prey upon cnidarians have evolved the ability to sequester nematocysts for their own defense. The nudibranch gastropod *Berghia stephanieae* is an emerging research organism that possesses the ability to sequester immature nematocysts from the anemone *Exaiptasia pallida*. Nudibranch sequestration is not well-studied; we do not fully understand how the animal is able to recognize the foreign organelles (and differentiate immature from mature) and incorporate them into its own cells. Nematocysts are endocytosed from digested food by specialized cnidophage cells that

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are housed in an organ called the cnidosac, which resides at the tips of cerata (dorsal appendages that contain branches of the digestive system). The proximal section of each ceras (plural: cerata) contains digestive tissue, whereas the distal section contains the cnidosac and cnidophages. Differential expression (DE) analysis was conducted on distal and proximal cerata, using four different bioinformatics analysis packages, to find 105 differentially expressed genes. Of these 105 genes, 35 genes were upregulated in the distal cerata. All of these genes were blasted against the NCBI database to show 70% of the transcripts had significant hits. Among the upregulated genes were macrophage mannose receptor 1-like (known to be involved in coral and dinoflagellate symbiosis) and WNT-9A (important in embryonic development, particularly cell fate, proliferation and migration). These two genes may be involved in the recognition of immature nematocysts and development of the cnidosac, respectively. In the near future, tools like whole mount in-situ hybridizations will be developed to verify the location and expression of these genes.

P14-8 Biondi, AA*; Flammang, BE; New Jersey Institute of Technology; *aab53@njit.edu*

Teaching a hands on, interactive course remotely in a socially distanced world

With the sudden transition to virtual learning due to COVID-19, teaching a hands on lab course while conserving the interactive relationships between the students and the lab specimens has become a hurdle for instructors around the globe. To minimize the changes from in-person to digital, we have created a virtual laboratory for our Comparative Vertebrate Anatomy course. Using Google Slides and Bitmoji instructors to create the virtual classrooms, we embedded links into images of the specimens that link to interactive 3D models from SketchFab, oVert, HHMI, MorphoSource, and YouTube. Here we present our methods in instructional format. Using our virtual laboratory, we were able to maintain the same level of learning objectives as compared to previous in-person semesters.

P39-2 Bistritz, L*; Viteri, MC; Hadly, EA; The Hebrew University of Jerusalem, Israel, Stanford University,

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California; *liraz.bistritz@mail.huji.ac.il*

Small mammal community dynamics in serpentine grasslands in California

Despite accounting for only 1% of land cover in California, serpentine grasslands support 13% of the state's endemic plant species. Although there have been many studies on the floral composition and structure of these grasslands, few have investigated the native small mammals that rely on this rare habitat type. We here study the dynamics of a small mammal community from a serpentine grassland at Jasper Ridge Biological Preserve in Woodside, California using barn owl (*Tyto alba*) pellets. 253 pellets were collected regularly between fall 2007 and summer 2008. From these pellets, at least 670 small mammal individuals from 9 species were identified from craniodental remains. We analyzed the trends in species abundances on two temporal scales: seasonal and monthly. When looking at seasonal changes the two most abundant species, *Microtus californicus* and *Reithrodontomys megalotis*, exhibited parallel fluctuations in abundance, peaking in the winter and declining through spring and summer. However, at the monthly scale we found negative associations in their abundance, which could stem from a competitive dynamic that was observed in previous studies in non-serpentine grasslands. Our study shows that this competitive dynamic is consistent across both serpentine and non-serpentine grasslands as well as emphasizes the importance of analyzing community dynamics at multiple resolutions.

P5-12 Bock, AK*; Burton, RS; University of California, San Diego; *akbock@ucsd.edu*

Hatching delays in extreme salinities in the intertidal copepod Tigriopus californicus

Living in tidepools in the supralittoral zone, all life stages of the copepod *Tigriopus californicus* must contend with salinity extremes, ranging from nearly freshwater after rainfall to near salt saturation (> 100 psu) in warm dry summer months. While mechanisms and limits of survival under extreme salinity conditions have previously been characterized in this species, impacts of salinity on reproduction have not been widely assessed. Here we report that *T. californicus* exhibits substantially delayed hatching

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of fully developed egg sacs under hypersaline conditions. In *T. californicus*, egg sacs remain attached to females and transition from dark green to red over the course of development, providing a visual indication of the status of the embryos. The production and development of egg sacs is delayed with increasing salinity (effects seen at 60, 70, and 80 psu versus 35 psu control), and at the highest salinities (80 psu) completely developed egg sacs may delay hatching for weeks until they are moved to more moderate salinities, where they typically hatch within 24 hours. Female copepods acclimated to and fertilized in 70 psu also show a reproductive delay in that salinity, but recover when returned to seawater, suggesting a potentially limited role for acclimation. These salinities are substantially lower than the median lethal high salinity found in previous work on adult male *T. californicus*, emphasizing the importance of measuring effects both on survival of individuals and on their reproduction in assessing impacts on population dynamics. Such delays in hatching of fully developed embryos have not previously been shown in *T. californicus*, although delayed hatching in response to salinity or other stressors is known in other copepods.

P11-7 Bollinger, L*; Dickie, R; Towson University; *lbolli4@students.towson.edu*

Induced antiangiogenesis diminishes vascularity in regenerating axolotl tails but does not limit early tail regrowth

Vatalanib, a small molecule inhibitor of vascular endothelial growth factor receptor tyrosine kinases, is used in this experiment to inhibit blood vessel formation in the regenerating tails of axolotls. *Ambystoma mexicanum* is known for its remarkable capacity to regenerate severed appendages, making it an ideal organism in which to assess regenerative abilities in the absence of angiogenesis in the proliferative vs. maturation phases of tissue outgrowth. Here, we evaluate the relationship between vascularization and tissue outgrowth in terms of rate, outgrowth area and morphological quality of the regenerated tail. Comparison of the tail growth for each group shows no significant difference in the rate of tail regeneration (0.083mm/day vs 0.085mm/day for treatment vs. control, respectively) despite differences in vascularity. The data suggest little requirement for

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neovascularization in early tissue growth as both the control and treatment groups displayed comparable regenerative rates and outgrowth areas. The slight differences in tail morphology may, however, indicates the greater importance of angiogenesis in the later phases of tissue regrowth. This work provides a better understanding of the role of blood vessel formation on tissue renewal in a major regenerative species.

P28-6 Bond, CE*; Kocot, KM; University of Alabama, Tuscaloosa; *cebond@crimson.ua.edu*

Determining the biodiversity of Wirenia (Mollusca, Aplacophora) in the northeastern atlantic

Aplacophorans are small, worm-like molluscs that lack a shell but possess calcareous sclerites instead. About 400 species have been described to date but there are likely many more that have yet to be discovered. Moreover, some known species may represent "cryptic species," which are morphologically identical, but different genetically. *Wirenia argentea* is an emerging model organism in aplacophoran research that is easily collected and can be spawned in the lab. However, previous work revealed at least one cryptic species that may co-occur with *Wirenia argentea*, raising concern that our experiments might be conducted on two or more genetically distinct species. In order to characterize the diversity and evolution of *Wirenia* in the Northeastern Atlantic, we imaged specimens collected during the IceAGE cruises using stereo light microscopy and selected a subset of specimens from throughout the Northeast Atlantic for high-resolution imaging using scanning electron microscopy (SEM). From there, we extracted high-quality DNA from the same specimens and sequenced fragments of the mitochondrial 16S and COI genes and the nuclear H3 gene. Maximum likelihood and species delimitation analyses reveal that there are 7-24 different species, depending on the approach used, compared to the two species described in the genus to date. Because SEM data were collected for every specimen, we were able to re-examine our morphological data and identify characters that help us identify at least some of these "cryptic" species. By knowing which species of Aplacophora live in which regions of the ocean and the species' biodiversity, it allows for more targeted access in future

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experiments and helps ensure that cryptic, co-occurring species are not being inadvertently compared in experiments.

P3-3 Bosque Ortiz, GM*; Leao, D; Dietrich, MO; Yale University, New Haven, CT, Federal University of Rio Grande do Sul Porto Alegre, Brazil ; *gabriela.bosque.ortiz@yale.edu*

Hypothalamic POMC neural modulation of infant vocalization in mice

Hypothalamic POMC neural modulation of infant vocalization in mice: Infants vocalize when isolated from their primary caregivers, attracting their attention to receive comfort, care, and nutrition. Impaired infant vocal behavior can lead to maternal neglect and even death in some species. Despite the importance of infant vocalization for the proper development of individuals, we still know little about how the brain controls this behavior. Beta-endorphin is an opioid that is strongly implicated in infant-caregiver bonding and is only synthesized by POMC neurons which are mainly found in the arcuate nucleus of the hypothalamus. Therefore, our aim was to determine the role of POMC neurons and beta-endorphin in the suppression of infant vocal behaviors. Our approach was to quantify ultrasonic vocalizations (USV) of infant mice during isolation and maternal reunion under genetic, pharmacologic and chemogenetic conditions. While the hypothesis of this study was that beta-endorphin is released by POMC neurons upon social reunion, leading the suppression of infant vocalization; our results lead to a different conclusion. Our data suggests that beta-endorphin does not suppress USVs during maternal reunion and instead is released after prolonged isolation, lowering the vocal rate of infant mice. For our next experiments, we will further elucidate beta-endorphin role during isolation and its possible interaction with other hypothalamic neural groups. Understanding the mechanisms driving infant vocalization is key to reveal how the infant brain regulates behaviors and to study disorders impacting early social and speech development. Bosque Ortiz GM, Yale University, New Haven, CT, gabriela.bosque.ortiz@yale.edu Leao D, Federal University of Rio Grande do Sul Porto Alegre, Brazil Dietrich MO, Yale University, New Haven, CT

P28-11 Bouguerche, C*; Tazerouti , F; Delphine, G; Justine, JL;

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Université des Sciences et de la Technologie Houari Boumediene, Faculté des Sciences Biologiques, Laboratoire de Biodiversité et Environnement: Interactions - Génomes, Alger, Algérie, Service de Systématique Moléculaire, Muséum National d'Histoire Naturelle, Paris, France, Institut Systématique Évolution Biodiversité, Muséum National d'Histoire Naturelle, Paris, France; *chahinezbouguerche@gmail.com*

Tell me what you eat, I'll tell you what are! A study of a hyperparasite Cyclocotyla bellones (Monogenea, Platyhelminthes) using integrative taxonomy

Cyclocotyla bellones Otto, 1823 is a monogenean characterized by an outstanding way of life. It is a hyper parasite that attaches itself to cymothoid isopods, themselves parasites of the buccal cavity of fishes. *Cyclocotyla bellones* was found on *Ceratothoa parallela* (Otto, 1828), an isopod parasite of *Boops boops* off the Algerian coast. We used integrative taxonomy by combining a morphological description of *C. bellones* with a molecular analysis carried out on COI mtDNA sequences. We provide, for the first time, molecular barcoding of a hyperparasitic monogenean, the parasitic crustacean host, and the primary fish host. Observation of indigestible haematin, a characteristic of fish blood, in walls of the intestine of *C. bellones* suggests that *C. bellones* feeds on fish blood. The body shape of various diclidophorids from fish gills or parasitic isopods was compared; we conclude that the anterior stem of the body of C. bellones is an anatomical adaptation for nutrition of the monogenean on the host fish. *>Cyclocotyla bellones*is thus a hyperparasite in terms of location (it dwells on a parasite), but not in terms of nutrition (it does not feed on a parasite but on the primary host).

P10-4 Bowsher, JH*; Wilson, ES; Rinehart, J; Murphy, CE; Wong, C; Grula, CC; Rinehart, JP; North Dakota State University, University of California, Davis, USDA-ARS; *julia.bowsher@ndsu.edu*

Maternal influence on offspring body size in the alfalfa leafcutting bee, Megachile rotundata

Body size strongly predicts fecundity and flight performance. In solitary bees, the mother controls the amount of food available for larval growth through provisioning. The mother also determines the sex of offspring and the environmental conditions of larval growth

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by choosing a nest site. In Megachilid bees, heritability of body size is low. Therefore, mothers may be able to determine the body size of offspring and make life history choices accordingly that maximize fitness. However, the amount of variation in body size determined by maternal nesting behaviors has not been well established. We measured provision size, position of the brood cell in the nest, diapause status, temperature during the larval stage, sex, adult body weight and intertegular span in field-collected nests of *Megachile rotundata*. Mothers gave diapausing offspring, female offspring, and those laid first in the nest larger provisions. Provision size alone predicted 18% of the variation in adult body size. Adding other significant predictors of body size including sex, diapause status, and position in the nest increased the R2 to 48%. Temperature of the nest during the larval stage did not affect adult body size even though some nests spent multiple hours above 40C, which is known to be a stressful temperature. The size of provision did not affect survival. Our results suggest that *M. rotundata* mothers are able to determine about half the variation in the adult body size of their offspring through provisioning and nest building behaviors.

P7-1 Brainard, CR*; Summers, D; Cohen, KE; Kruppert, S; Summers, AP; Kolmann, MA; UMBC, Harvard Universiy, University of Washington, University of Washington, University of Michigan; *cbrain1@umbc.edu*

Flexible armor: overlap and microstructure of poacher (Agonidae) armor

Defensive armor has repeatedly evolved among animals. There is a trade off between flexibility and defense, and heavy armor is costly due to the energetic investment of swimming with, maintaining, and growing densely mineralized scales or plates. Armor can also stiffen the body for locomotion or serve as an elastic storage mechanism. Each role has an influence on what the armor is made of, and how elements connect and interact. Poachers (Agonidae) are cottoid fishes with heavy, overlapping armor plates that provide protection from harsh environments, aggressive conspecifics, and predators. The overlapping nature of these armor plates ensures there are no gaps in protection, while still facilitating locomotion. We measured plate overlap from micro-computed tomographic scans of straight and bent spearnose poacher

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(*Agonopsis vulsa*). We described the microstructure of the plates and the area between plates by sectioning and staining. There is considerable antero-posterior overlap (~15% plate area) among plates in compression, and in tension there is less overlap (~7% plate area). Differences in lateral overlap were negligible between bent (compression) and straight specimens, but increased between rows when in tension. Overlap among neighboring plates varies in magnitude depending on the direction of overlap. For example, the degree of movement in an antero-posterior direction is more limited than lateral overlap due to a tongue and groove rail system along the underside of the plate's surface. Histology shows that *A. vulsa* scales are primarily composed of acellular bone and there is connective tissue between overlapping plates. The presence of this connective tissue, which may act as an elastic brake, implies a sophisticated system of movement and positioning between plates during bending.

P13-4 Brandon, AA*; Martin, KT; Powder, KE; Clemson University; *aabrand@clemson.edu*
Craniofacial sexual dimorphism in cichlids is species-specific and occurs during development
The craniofacial skeleton is one of the most sexually dimorphic traits in humans, showing shape differences in structures such as the jaw. The molecular mechanisms that facilitate this variation between males and females, and when in development these differences arise, are unknown. To determine the pattern of craniofacial sexual dimorphism, we conducted geometric morphometric shape analysis on craniofacial structures in five species of Lake Malawi cichlids. These fish have undergone an adaptive radiation resulting in closely-related species presenting a spectrum of craniofacial morphologies based on different trophic strategies (biting versus suction-feeding), making them ideal models for studying species- and sex-specific craniofacial variation. Although there were larger effects of species and age, we found that sex is a significant contributor to bone shape. For example, $p=1.1e-12$ for species, $p=7.8e-6$ for age, and $p=0.04$ for sex on analysis of the lateral mandible. Notably, differences in overall lateral and ventral craniofacial shape between males and females differed between species. Together, these suggest that both sex, and

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interactions between species-specific genetics and sex, are contributing to the incredible craniofacial diversity present in these species. We found that manipulation of estrogen and progesterone hormone signaling during early bone patterning has a significant effect on craniofacial shape. This suggests a possible molecular mechanism that underlies sex dimorphism, and highlights the importance of hormone signaling in bone development before puberty. Altogether, we find that sexual dimorphism significantly contributes to phenotypic variation in the face, has distinct patterns in animals with alternate feeding strategies, and may occur through variation in hormone signaling.

P17-12 Brewer, ME*; Root, ZR; Medeiros, DM; University of Colorado Boulder; *brewermargaux@gmail.com*

Tendon development in lamprey and its implications for vertebrate morphological evolution

Tendons mediate muscular-skeletal junctions in vertebrates and are key to movement and stabilization of muscles. The evolutionary origins of tendons are unclear, as they are absent in invertebrate chordates and are thus vertebrate novelties. We chose to look into the developmental origins of tendons in cyclostomes, specifically sea lamprey, an understudied vertebrate group which diverged from other vertebrates more than 500 million years ago. It is known that lamprey have true muscles and skeleton based on marker gene expression data and histochemical studies. We hypothesize, therefore, that tendons are a fundamental structure to the vertebrate musculoskeletal system and that this cell type existed in the last common ancestor of lamprey and gnathostomes. To test this, we investigated tendon development in embryonic sea lamprey *Petromyzon marinus*. We selected seven different genes that are known to be factors in tendon development in gnathostomes (Psx, Mkx, Xirp2, Egr1, Col3a1, Col1a2, Col12a1). We used in situ hybridization paired with sectioning and histochemical techniques to analyze when and where these tendon marker genes are expressed in the sea lamprey embryo. Our results found that tendon marker genes are spatially and temporally distributed throughout the embryonic lamprey body- expressed in the myosepta, myomeres, facial muscles, pharyngeal muscles, and pharyngeal skeleton at various stages in development and in both muscle and skeletal cell types.

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We note the presence of multiple tendon marker genes in a muscle thought to be unique to lamprey: the hypobranchial muscle. We discuss implications of this spatial, temporal, and cell-type mixture of tendon marker gene expression for vertebrate musculoskeletal evolution.

P31-8 Brocco French, KI*; German, DP; University of California, Irvine; *kbroccof@uci.edu*

Effect of toxins on host microbiomes in an echinoderm keystone species as an indicator of ecosystem health

In the 1950's, the shipping industry began painting ships with antifouling chemicals called triorganotins (TBTs). Though outlawed in the U.S., TBTs are used illegally, leach from old paint, and persist for decades in sediment. Ingestion and exposure to TBTs causes inhibited growth and development in a wide range of marine invertebrates. Despite the emerging importance of the Holobiont theory, little information examining how TBTs may induce dysbiosis and/or facilitate inoculation by new and/or harmful microbes into the bodies of marine invertebrates exists. Echinoderms are ideal model organisms to study the effects of TBTs on host development because they undergo complex life cycles, including a larval stage especially vulnerable to predation and to relatively low concentrations of TBTs. We are using transcriptomics and 16s rRNA sequencing to understand how *Strongylocentrotus purpuratus* larvae benefit from their microbiomes and how ontogeny and/or toxins affect the holobiont. In collaboration with Cabrillo Marine Aquarium, we are rearing *S. purpuratus* larvae with ecologically relevant doses of TBT. Same life-stage individuals will be sampled in batches of 10 ensuring sufficient microbial DNA and sufficient host RNA. We will sample larvae through time and track morphometrics and mortality rates. Corresponding microbiomes and host transcriptomics will be examined. We predict that the microbiome of *S. purpuratus* will shift in species composition across developmental stages since microbiomes vary with morphology and diet within echinoderm host species. Additionally, we expect TBTs will disrupt the metabolic pathways maintaining host health and host-microbial interactions in *S. purpuratus* because toxins affect echinoderm growth and development. Because *S. purpuratus* are

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a keystone species, host-microbial research will serve as an indicator for the health and resilience of the rocky intertidal.

P36-7 Bronstone, GJ*; Bauer, DE; Harling, M; Muldowney, M; Funk, AJ; Reigle, J; Meller, J; O'Donovan, SM; McCullumsmith, RE; Wellesley College, MA, University of Toledo College of Medicine, OH, University of Cincinnati, OH; *gbronsto@wellesley.edu*

How glutamate transporter deletion influences behavior, longevity, and protein expression in Caenorhabditis elegans

The neurotransmitter l-glutamate (Glu) plays a powerful role in many biological functions including behavior, lifespan, and metabolism. Glutamate transporters mediate extracellular Glu accumulation among neurons and glia to prevent excitotoxic neurotransmission and consequent neuronal damage and cell death. The effect of singular transporter deletion on behavior, lifespan, and proteomics remains largely unexplored despite extensive research on glutamatergic signaling pathways, so we knocked out Glt-4 and Glt-5 in the invertebrate *Caenorhabditis elegans*. Glt-5 mutant strains demonstrated minimal behavioral divergences with wildtype in sharp contrast to severe behavioral deficits observed in Glt-4 mutants. We also investigated the role of GluTs in mediating C. elegans lifespan characteristics. Glt-4 mutants exhibited decreased lifespan while Glt-5 mutants had increased longevity when both were compared to wildtype *C. elegans*. A global mass-spectrometry based approach identifed changes in protein expression that may account for the increased longevity precipitated by Glt-5 deletion. Proteomic results showed Glt-5 deletion affects a number of enzymes related to metabolism, stress response, cellular structure, movement, and development. Remarkably, the Glt-5 mutant strain expresses considerable upregulation of specific metabolic genes. We propose that Glt-5 mutants both optimize and maintain integral cellular functions above baseline levels as deletion of Glt-5 incites favorable changes in the C. elegans proteome.

P15-6 Bryant, AR*; Gabor, CR; Texas State University; *arb326@txstate.edu*

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Examining the effects of conventional and organic agriculture on capacity to cope in larval grey treefrogs (Hyla versicolor)
Conventional agricultural inputs can have a variety of negative effects on physiology and fitness, which contribute to population declines. Organic agriculture is often proposed as a means of increasing sustainability while minimizing negative impacts on wildlife. In amphibians, the physiological response to external perturbations is controlled by the hypothalamus-pituitary-intrarenal (HPI) axis, which regulates the release of the glucocorticoid (GC) hormones. When individuals are repeatedly exposed to stressors throughout their lives, maintaining the capacity to cope with persistent stressors is crucial. If repeated exposure dysregulates the HPI axis, then pathological effects may impact fitness and can lead to death. In such cases, altering the GC profile (both the stress response and recovery) may aid with coping but may come at costs to fitness measures. Studies thus far have not found significant differences between the impacts of organic and conventional inputs on biodiversity or fitness indicators, but no study has examined the endocrine profiles. We hypothesized that the capacity to cope with stressors in larval gray treefrogs (*Hyla versicolor*) would differ across ponds near conventional, organic, and natural agricultural fields. We used non-invasive water-borne hormones to measure the GC profile of 16 individuals from 3 ponds in each treatment. We predict stronger stress response and quicker recovery in tadpoles from ponds with organic and conventional inputs than natural ponds. These tadpoles may suffer greater fitness costs associated with the agricultural inputs including lower body condition and more parasites.

P31-1 Bueren, EK*; Weinheimer, AR; Aylward, FO; Hsu, BB; Bradford, EL; Haak, DC; Belden, LK; Virginia Tech; *ebueren@vt.edu*
Characterization of prophages in the honey bee gut
Most host-associated viruses are bacteriophages (phages), which infect bacteria rather than eukaryotic organisms. Early research indicates that phages may play a role in regulating a host's gut microbiome, which in turn may impact host health. Phages have two types of lifestyles: lytic and lysogenic. Lytic phages immediately replicate within and destroy bacteria, while lysogenic phages integrate into bacterial DNA and form a prophage, which replicates

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with the bacteria until environmental triggers induce lysis. Prophages can also encode useful toxins or metabolic genes within bacteria. The complexity of most animal microbiomes can make bacteria-prophage interactions difficult to study. However, the European honey bee (*Apis mellifera*) has a relatively limited and well-characterized set of core gut bacteria. Approximately 200 genomes (fragmented and complete) from honey bee gut-associated bacteria are published on NCBI, representing isolates from all nine major phylotypes and two bacterial pathogens. We conducted an initial survey of prophages in the honey bee gut by analyzing these 200 genomes through two different phage hunting tools: ViralRecall and PHASTER. High confidence phage candidates were identified. Our initial results indicate that the number of prophages within an individual genome varies between bacterial genera, with an approximate range of 0 - 9 phage regions per genome. Prophage per genome was highest among the pathogen *Paenibacillus larvae* (causative agent of American foulbrood) and in the core microbiota *Snodgrassella alvi* and *Gilliamella apicola*. This initial survey is the first step in understanding how the prophage community interacts with, and possibly modulates, bacterial communities in the honey bee gut.

P7-8 Buo, C*; Garner, AM; Londraville, RL; University of Akron, Akron, OH; *cb46@zips.uakron.edu*

A histological study of the blue-dashed rockskipper (Blenniella periophthalmus)

Blue-dashed rockskippers are a combtooth blenny found in intertidal areas of Indo-Pacific waters. These amphibious fish exhibit jumping behaviors and adhesive ability on both rough and smooth surfaces. We were interested in investigating the morphological mechanisms responsible for the adhesive capabilities of these fish, particularly since very little work has been published on this species. Histological staining of integumentary tissue from both the ventral and lateral areas revealed very little muscle but a relatively thick layer of dense collagen in the dermis. We propose that this layer of dermal tissue assists the fish in adhesion through an ability to conform to the surface in conjunction with mucous to create a contact area large enough to allow for adhesion.

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P14-4 Byrd, MA; Hedrick, TL*; University of North Carolina at Chapel Hill, Chapel Hill, NC; *thedrick@bio.unc.edu*

2D and 3D video digitizing with a web browser

Many data collection workflows throughout integrative and comparative biology use video recordings as a measurement method. Furthermore, the ever-improving capabilities of smartphones now place high resolution and slow-motion video recording capabilities in the pockets of many high school and undergraduate students. However, analyzing video recordings to produce research data has commonly required installing and learning to use specialized software, adding an additional hurdle to overcome in contexts such as remote learning where video might enable at-home lab experiments but access to video analysis software is limited. Furthermore, the desktop application paradigm traps the resulting data products on a single computer where they may be difficult to share. Here we present an open-source web-based video digitizing and annotation program authored in JavaScript that runs in any modern browser. Our tool enables 2D marker annotation in multiple videos and supports 3D reconstruction via direct linear transformation. The video files themselves are accessed locally but can potentially be uploaded to the server for later re-downloading to enable project portability. User-generated video digitizing data are stored on the server but can be downloaded in text or JSON format. In addition to working with the browser software already present on student computers, the client-server model also potentially facilitates use of Deep Learning and other computationally intensive analysis methods that would not typically be available on these devices. While end-users currently find it difficult to install these tools or to marshal the necessary resources, these could be coordinated from the server. Finally, improvements to our tool are ongoing and the nature of a web applications ensures that all users immediately get the benefit of any future improvements.

P12-3 Calderon , JA*; Sustaita, D; California State University San Marcos; *calde047@cougars.csusm.edu*

Comparison of grasping and biting forces among rodent species in the Suisun Marsh, California

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Studying functional performance in rodents can help us understand how they use their habitat. For example, studying bite force might help us understand their feeding ecology. Similarly, studying grasping force might help us understand their climbing abilities. However, not much is understood regarding how biting and grasping forces vary among species that occupy the same habitat. We measured grasping and biting forces of four different species found in the Suisun Marsh, including the endangered salt marsh harvest mouse (*Reithrodontomys raviventris halicoetes*), western harvest mouse (*Reithrodontomys megalotis*), California vole (*Microtus californicus*), and house mouse (*Mus musculus*) using a force transducer. In addition, we measured the relative sizes of the forefeet and rostrum of each individual to explore anatomical correlates of these forces. According to our preliminary results, peak grasping and biting forces (scaled to body size) were greatest in the California vole, followed by the western harvest mouse, salt marsh harvest mouse, and house mouse. This pattern could reflect differences in foraging and/or locomotion, such as the voles' tendency to burrow and the house mouse's generalized behavior. Further morphological analyses suggest that manus surface area is positively correlated with grasping force, but rostrum length does not explain variation in bite force among individuals. These results help pinpoint key aspects of morphology that might be correlated to differences in feeding behavior and microhabitat use among species.

P34-7 Caldwell, MF*; Lopez-Perez, JE; Warner, DA; Wolak, ME; Auburn University, AL, Eckerd College, St. Petersburg, FL; *mmf0009@auburn.edu*

Consistent nest site selection by turtles across sites with varying levels of human disturbance

Human disturbance impacts the breeding behavior of many species, and it is particularly important to understand how human-caused changes affect vulnerable taxa such as turtles. Habitat alteration can change the amount and quality of suitable nesting habitat, while human presence during nesting may influence nesting behavior. Consequently, both habitat alteration and human presence can influence the qualities of a site that females select for nesting. In summer 2019, we located emydid turtle nests in Macon and Lee

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counties, AL, at three site types (high, intermediate, and low levels of human disturbance). We built linear mixed-effects models to determine the relationship between site type and maternal microhabitat selection, and to determine if turtles selected sites differently than what was randomly available. We found a significant effect of site type on the slope, canopy, and average nest temperature. Additionally, maternally-selected nest sites had less variance in canopy cover than randomly-chosen sites. Results suggest that turtles discriminate among abiotic factors when selecting nest sites, but that turtles are generally selecting sites with similar microhabitat at each disturbance level. These results suggest that turtles are not adjusting their nesting choices when faced with anthropogenic change, highlighting the importance of preserving natural areas.

P17-1 Camacho-Avila, AC*; Rogers, CD; California State University Northridge , UC Davis School of Veterinary Medicine; *alexis.avila.141@my.csun.edu*

Species-specific roles of Sox10 in the neural crest gene regulatory network

Species-specific roles of Sox10 in the neural crest gene regulatory network Avila, AC and Rogers, CD 1California State University, Northridge; 2University of California, Davis alexis.avila.141@my.csun.edu, crdrogers@ucdavis.edu Neural crest (NC) cells are embryonic stem cells that give rise to craniofacial bone, pigment cells, and the peripheral nervous system. Understanding the molecular mechanisms that regulate the formation of NC cell development is crucial to identify causes for abnormal vertebrate development. Several transcription factors function as mediators of NC specification and migration, including Sox10, Sox9, and Pax7. I characterized expression of multiple NC transcription factors in chicken and identified that while the spatiotemporal expression of the factors is conserved, the NC protein function may not be. Gain and loss of function studies determined that overexpression of chicken SOX10 is sufficient to induce ectopic expression of SOX9, but not PAX7 in chicken embryos, which is interesting because our preliminary data shows that chicken Sox10 is sufficient to induce the expression of other neural crest markers when expressed in quail. We induced chicken Sox10 in quail

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embryos and found it induced premature NC migratory cells, indicating Sox9 and Pax7. These studies increase our understanding of the mechanisms mediating NC development in vertebrates and highlight new tools that can be used in evolutionary development research.

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P11-1 Campos, CB*; Correa, MG; Collins, CE; California State University, Sacramento; *campos7@csus.edu*

Functional anatomy of tail regeneration in the California alligator lizard, Elgaria multicarinata

Preventing depredation is vital for survivorship and organisms have evolved a diverse repertoire of adaptations to escape predators. Caudal autotomy and regeneration are striking, coupled adaptations supporting many lizard species survival and evolutionary diversification. We studied the muscles and support structures in original and replacement tails of California alligator lizards (*Elgaria multicarinata*). We hypothesized regenerated tails exhibit structures that maintain movement capacity. We requisitioned samples of original (n=4) and regenerated (n=4) tails from the California Academy of Science Herpetology Collection and scanned them using a MicroCT scanner. Then, we dipped specimens in a custom-modified iodine solution to render the muscle tissue radio-opaque, and rescanned to visualize muscle tissue (DiceCT). Scans were analyzed and segmented in Amira 3D visualization software. Preliminary results indicate cartilaginous rods replace bony vertebrae and protective osteoderms (bony scales) appear smaller and less dense than originals. Muscles appear less organized and smaller. We anticipate that this species will show similar structure patterns and organization compared to previous studies. Yet muscle sizes should be relatively larger in this species, which uses its tail to move and balance. Results vary due to confounding factors in regeneration phase and environment. This study characterized the secondarily-simplified, regenerated structures by quantifying differences in bone, muscle, and cartilage of regenerated and original tails. Our results enhance our knowledge of appendage regeneration in vertebrates and provide a new model for biomedical and clinical applications including prosthetics and biomimicry. Funded by CSUS RISE R25GM122667.

P16-4 Cantelon, CL*; Kwun, C; Harmon, IP; McCabe, EA; Solomon-Lane, TK; Scripps College, Claremont McKenna College, Pitzer, Scripps, and Claremont McKenna Colleges; *tsolomonlane@kecksci.claremont.edu*

Stress axis correlates of juvenile social behavior and group structure in a highly social fish

Neuroendocrine stress axis function can provide important insight into variation in individual social behavior and group dynamics, for example, through reprogramming by early-life social experience and associations with status and behavior. We studied the behavior, group structure, and hypothalamic-pituitary-interrenal (HPI) axis of juvenile *Astatotilapia burtoni*, a highly social cichlid fish. Cortisol has important social interactions in adults, for example, with social status; however, cortisol has yet to be studied in juveniles. Juveniles express complex social behaviors, similar to adults, but social status and reproductive state differ. We formed social groups of 5 fish (8-11 weeks old) and measured water-borne cortisol and spatial position for each fish in three different environments. The environments consisted of a small, large, or no clay territory structure in the tank, which were designed to influence fish position. There was a significant interaction between the social group and average distance between fish, suggesting the territory had group-specific effects on spatial distribution. Fish also situated themselves on the outer boundary of the territory, rather than the center. Next, we tested whether and how variation in cortisol levels reflects variation in spatial position. We hypothesized that individuals occupying similar physical and social spaces across groups have similar cortisol levels, and highly dynamic groups have more variation in individual cortisol levels than more stationary or stable groups. This work can help uncover the role of stress axis function in behavior and development, as well as future effects on adult phenotype.

P40-5 Chantarawong, N*; Byron, ML; Pennsylvania State University; *nmc5415@psu.edu*

Boatmen and backswimmers and beetles, oh my: intermediate Reynolds number locomotion in aquatic insects

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Many aquatic organisms use drag-based propulsion methods. At low Reynolds numbers (Re), animals stop moving as soon as their appendages do—they do not coast or glide. However, some animals swim at intermediate Re, where viscous forces are balanced with inertial forces. Here, gliding becomes possible as the animals grow larger and swim faster. This transition from low to intermediate Re, though bridged by many animals, is not well-understood. We investigated the swimming kinematics of three specific families of freshwater insects with similar drag-based swimming techniques: water boatmen (Corixidae), backswimmers (Notonectidae), and diving beetles (Dytiscidae). We collected synchronized high-speed video of the three-dimensional swimming trajectories of these insects across a range of Re, from less than 10mm to over 20mm in length. We compared swimming and turning characteristics across all three species and a range of Re. We found that the 3D trajectories displayed a spectrum of discrete vs. continuous behavior, indicative of the important role of both viscous and inertial forces in the intermediate Re regime. Our results provide important insight into organism-environment interactions at the millimeter-to-centimeter scale and into intermediate Re swimming, which is not as well understood as low Re and high Re swimming. In light of recent developments in the miniaturization of sensors, devices, and robots, our results may also provide a platform for bioinspired engineering at intermediate Re.

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Occurrence of hyper-hypo osmoregulation during the post-embryonic development of the Asian shore crab Hemigrapsus sanguineus at an invaded site (North Sea, German Bight)

We studied the ontogeny of osmoregulation of *Hemigrapsus sanguineus* at an invaded area in the North Sea (islands of Helgoland and Sylt). This crab is native to the coasts of Japan and China but has successfully invaded the Atlantic coast of N America and N Europe. We reared larvae (zoea I to megalopa through five zoeal stages) and crab 1 at 24° C in seawater from hatching to

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intermoult of each developmental stage. At each stage, we exposed larvae and juveniles to a range of salinities (0-39‰) for 24h then we quantified haemolymph osmolality using nano-osmometry. We also quantified osmolality in field-collected adults after acclimation to the test salinities for 6 days. Larvae of *H. sanguineus* were able to hyper-osmoregulate at low salinities (15 and 20‰) over the complete larval development, although the capacity was reduced at the zoeal stage V; at higher salinities (25-39‰), all larval stages were osmoconformers. The capacity to hypo-regulate at high salinity occurred in crab 1 following metamorphosis. Adults were able to hyper-osmoregulate at low salinities and hypo-regulate at 39‰. *H. sanguineus* showed a strong capacity to osmoregulate as compared to its native competitor, *Carcinus maenas*, which only hyper-regulates at the first and last larval stages and does not hypo-regulate at the juvenile-adult stages. The capacity to osmoregulate over most of the life-cycle may confer a competitive advantage to *H. sanguineus* in areas were low salinity conditions are also characterised by high temperatures.

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Role of visual stabilization in home vector memory during path integration in fiddler crabs, Uca pugilator

Animal survival depends on the ability to orient and navigate in space while executing complex behaviors. One such spatial navigation mechanism is path integration, an innate process by which animals construct a memory of a location they have visited by encoding the distance and direction of their body movements, and summing them as vectors in an internal coordinate system to produce a single ‘home vector’. This home vector can be based in either a geocentric or an egocentric frame of reference. A geocentric reference seems intuitively clear, so here we asked, *what is the egocentric reference?* Where is, in animal spatial perception, front-and-center? Is it the longitudinal body axis? Fiddler crabs make an excellent model to study the nature of this spatial frame of reference, since they tend to align the transverse axis of the body with the direction of home, and so it has been proposed that their home vector is identical with the body axis. However, this

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cannot be strictly true since body axis is often not aligned with home. An alternative reference for the home vector, especially since it explicitly reflects the deviation of the body axis from home direction, is eye position. Optokinetic eye movements stabilize the eyes against body rotation. Thus, the hypothesis was that crabs remember the home direction as the body orientation plus the eye-body angle. To test this, the eye-body, eye-burrow, and body-burrow angles were analyzed in the presence and absence of visual structure in the surround. Since eyes were better stabilized in the presence of visual structure, the homing error was smaller compared to absence of visual stabilization, indicating the crabs' home vector is a combination of the body orientation and eye-body angle.

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Investigating the roles of the canonical Wnt and Notch signaling pathways in establishment of the tardigrade anteroposterior axis
The canonical Wnt (cWnt) signaling pathway plays a prominent role in establishing the anteroposterior (AP) body axis in many bilaterians. Later, this pathway typically interacts with the Notch signaling pathway and the transcription factor Caudal to regulate posterior growth. Tardigrades have lost posterior growth and the mid-trunk region that develop by this process.
Nonetheless, *caudal* is still expressed in the posteriormost region of the developing AP axis in the tardigrade *Hypsibius exemplaris*. We aimed to determine the roles, if any, of the cWnt and Notch signaling pathways during establishment of the highly compact AP axis of Tardigrada. Unlike in many bilaterians, *notch* and *Delta*, components of the Notch signaling pathway, are not expressed in a posterior domain immediately after establishment of the AP axis in *H. exemplaris*. These results argue against a role of the Notch signaling pathway in regulating growth of the AP axis in Tardigrada. Nonetheless, our data are consistent with a role of these genes in regulating nervous system development. However, expression of orthologs of *wnt2*, *wnt4*, and *wnt16*, which code for cWnt signaling ligands, are restricted to posterior regions during the earliest stage of AP axis establishment. We present a model in which the compact body plan of tardigrades evolved by conservation

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of the AP axis establishment function of the cWnt signaling pathway, with loss of the later acting posterior growth functions of the cWnt and Notch signaling pathways. Therefore, the AP establishment role of the cWnt signaling pathway, which operates before posterior growth intercalates a relatively large mid-trunk region in many bilaterians, may establish the entire AP axis in Tardigrada.

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Mapping spatiotemporal changes of North American beaver (L. Castor canadensis) trail and canal networks

Trails and canals emerge as beavers engage in dam building behavior. Trails form as vegetation is cleared by beavers. Beavers excavate canals by deepening trails, and these facilitate transportation of large, woody material. The dam building season in the Rocky Mountain west lasts three (3) to five (5) months. Canals can persist for years, and trails re-emerge every building season. This study tracks and quantifies beaver colony trail and canal construction and expansion in the foothills of the Rocky Mountains in northwestern Montana where spring floods annually wash out previous years' builds, requiring beavers to rebuild from "scratch." To observe trail and canal networks at high spatial and temporal resolution, we used a DJI Phantom 4 Pro drone to scan three (3) sites from May 2018 to August 2018. Using Agisoft Photoscan, we constructed high resolution (1.3 cm/px) orthomosaics. At each site, about one (1) scan per month was annotated with ArcGIS to create shapes files in order to track trail and canal lengths. We found that most colonies experienced a linear increase of trail and canal growth during the observed period. Trail formation preceded dam building by beavers. Among the 17 colonies identified, average trail and canal network length grew by about 5 km, and three (3) colonies exceeded 10 km of growth.

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Stuck in a bucket: The effect of confinement stress on cortisol levels in brook trout (Salvelinus fontinalis)

In vertebrates, a primary physiological stress response is characterized by a rapid increase in circulating glucocorticoid levels. Repeated exposure to external stressors can have an impact on overall health, such as metabolism, growth, and immunity. Salmonids are a cold-water fish found in higher elevations; they are important both environmentally and recreationally. Brook Trout, Salvelinus fontinalis, prefer open, clean environments but are often exposed to stressful confinement in hatcheries. The goal of this study is to examine the primary stress response that fish experience during confinement. We investigated the effect of physical and visual stressors on cortisol levels in fingerling brook trout. Wild-caught fish were acclimated in a lab for 6 months. On the day of the experiment, we compared two different routes by which systemic cortisol levels could be collected: water-borne and plasma. On the day of the experiment, fish were held in a smaller confined bucket for one of the following time periods: 3, 5, 15, 30, or 60 mins and then a blood sample was obtained. Steroid samples were extracted from both water and plasma through solid phase extraction, and cortisol measured using an enzymeimmunoassay. We predicted a steady increase in cortisol levels over the five-time points. Preliminary data show a steady increase in cortisol throughout the 60 min period with a more exponential increase between 30 and 60 mins. These data will be important to determine the time frame of the stress response resulting from confinement stress, develop a non-invasive method of systemic hormone measurement, and help assess other negative effects of chronic stress in salmonids.

P39-13 Clark, D*; Pechenik, JA; Robbat Jr., A; Tufts University; *daria.clark@tufts.edu*

Exploring the effects of toxic red tide algae (Karenia brevis) on development of the marine snail Crepidula fornicata

Toxic red tide algae are a widespread and growing threat to aquatic ecosystems, fishing economies, and human health. One particular red tide algal species, *Karenia brevis*, produces neurotoxic chemicals called brevetoxins, which can cause massive fish kills along with the poisoning of humans who ingest brevetoxin-contaminated seafood.

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We conducted several experiments to assess the effects of exposure to *K. brevis* on the survival, growth, and development of *Crepidula fornicata*, a species of marine snail that is common in the Gulf of Mexico, where *K. brevis* regularly blooms, and whose larvae, juvenile, and adult life stages are a potential prey source for many commercial species that reside there. In addition to its overlapping range with *K. brevis*, *C. fornicata* has become a prolific invasive species in many parts of the world and is being considered as a potential aquaculture species in its own right. We exposed *C. fornicata* larvae to medium and high bloom concentrations of *K. brevis* and looked at the impact on larval survival, shell length, shell weight, tissue weight, feeding rates, and metamorphosis. While there were no significant effects of *K. brevis* exposure on the short-term survival of *C. fornicata* larvae, there were several concentration dependent sub-lethal effects, including slower larval growth rates, elevated feeding rates, and lower response to cues for metamorphosis. Slower growth and reduced metamorphosis both extend the amount of time spent in the larval veliger stage, which could increase the vulnerability of *C. fornicata* larvae to predators and has implications for the dispersal and settlement of the species. Exposure to brevetoxins during the larval stage also has the potential to impact post-metamorphic survival and growth.

P11-4 Clark, JV*; Clark, CM; Stanford University, Harvey Mudd College; *jvclark@stanford.edu*

Modeling flight dynamics in gliding lizards

The ability to glide, climb, and run effectively is unique in the animal kingdom. *Draco*, a genus of flying lizards native to southeast Asia, attaches the leading edge of its patagial membrane, which functions as a wing, to its forelimbs, hence forming a "composite wing". This allows full terrestrial running ability as well as long distance gliding. However, it is currently unknown how *Draco* lizards are able to maneuver effectively during flight. Prior studies have hypothesized that this "composite wing" gives *Draco* its ability to navigate mid flight and maintain body position while gliding long distances. In this work, it is theorised that the tail, which accounts for approximately 60% of the lizards' length, also plays a pivotal role in glide

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maneuverability. We first modeled the *Draco* flight dynamics as a function of gravitational, lift, and drag forces. Lift and drag estimates were derived from wind tunnel experiments of 3D printed models based on the mass and geometry of *Draco maculatus*, a mid-sized *Draco* species with relatively low wing loading. Initial modeling leveraged the known mass and planar surface area of the *Draco* to estimate lift and drag coefficients. We developed a simplified, three-dimensional simulation for *Draco* flight, calculating longitudinal and lateral position and pitch angle of the lizard with respect to a cartesian coordinate frame. We used PID control to model the lizards' tail adjustment to maintain pitch angle. Our model suggests *Draco* could predominantly use its tail to adjust its center of gravity in real time in order to maintain a desired angle of attack and control glide distance. This simulation will be further developed in the future using different physical models to more accurately measure lizard flight, in order to determine the effect of the tail on how *Draco* is able to maneuver mid-glide.

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Movement behavior in the sand dollar Mellita tenuis

The sand dollar *Mellita tenuis* occurs in large aggregations in nearshore environments in the eastern Gulf of Mexico, numbering in the tens per m2. Due to their high density, they are considered major bioturbators of their environment. In this laboratory study, individuals of *M. tenuis* collected from Pensacola Beach, Florida, USA were placed in an enclosure under varying treatments (time of day, feeding history, predator presence, density, size), and video recorded for 3-4 h. The recordings were analyzed for the percentage of time in bioturbation (forward and rotational movement), percentage of time in progression (forward movement), percentage of time covered by sand, distance moved, and overall velocity. Contrary to existing literature, there was no significant diel rhythm found for any of the variables studied amongst time-of-day treatments (12 am, 6 am, 12 pm, and 6 pm). When alone, neither feeding history nor predator presence had an effect; however, size affected covering, distance, and velocity, with large individuals covered less often, and moving farther and nearly two times faster

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than small individuals. Additionally, lower density aggregations spent more time in bioturbation than higher density aggregations.

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Phenotypic impacts of warming environments: Morphological differentiation in a Death Valley pupfish parallels plastic developmental response to high temperature

Temperature is known to alter physiology and behavior in fish, but also has potential to alter morphology by impacting development and growth. In 2010, a population of Amargosa pupfish (*Cyprinodon nevadensis amargosae*) from a groundwater fed spring named Tecopa Bore in the Death Valley region of California, USA, experienced a mean temperature elevation of approximately 9° C following an anthropogenic alteration to its habitat. That temperature increase was accompanied by a 36% reduction in mean mass, 7.6% reduction in body length, and the partial or complete inhibition of paired pelvic fin development in 34% of the population. To further evaluate how higher temperatures influence morphology in pupfish, we compared body shape variation of Amargosa pupfish collected in 2013-2017 from Tecopa Bore to a conspecific allopatric population from the nearby, variable temperature Amargosa River. Pupfish in Tecopa Bore were again smaller, showed a reduced incident of pelvic fins, and also exhibited a proportionally larger eye and head. That combination of characteristics mirrors previously observed outcomes of plastic phenotypic responses of *C. n. amargosae* to high temperature in laboratory studies, suggesting that morphology of pupfish in Tecopa Bore may have emerged in part from developmental plasticity. Pupfish from Tecopa Bore also exhibited reduced sexual dimorphism in body depth compared to the river population, suggesting high temperature may also affect sex differences in shape. These observations implicate temperature variation having contributed to morphological divergence between the Tecopa Bore and Amargosa River populations, and point to the importance of considering how warming temperatures may affect morphology in other fishes.

P21-2 Cohen, KE*; Komann, MA; Friday Harbor Labs, University of

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Differences in the histological composition of piranha and pacu lips are consequences of prey manipulation tactics

The role of soft tissues in prey processing or prey manipulation are critical to vertebrate feeding performance, extending beyond the musculature to ligaments, tendons, and even less-conspicuous composite organs like lips and tongues. The usefulness of soft tissues during feeding is best captured from studies on terrestrial mammal foraging, where prehensile lips are used to defoliate branches or tongues used to reposition a bolus during feeding. Here, we used histological sectioning to compare lip morphologies among seed-eating and grazing pacus, as well as carnivorous piranhas (Serrasalmidae). We suspect that the pacu's hypertrophied lower lip could behave actively during feeding, manipulating plant parts like a rhino's prehensile tongue. Alternatively, the lower lip could act passively, with rugosity lending better grip on fruits and seeds. If the former is the case, our histological methods should find extensive musculature around the circumference of the lip, while the latter hypothesis implies little, if any muscle will be present. The lips of pacus are composites of collagen, fat, putative sensory nerves, and macrophages. Grazing pacus such as *Tometes* and *Myloplus* have slick lips filled with goblet cells that may resist abrasion and shear from caustic plant material, whereas the lips of fruit-eating pacus like *Piaractus* have a dense, highly folded epithelium followed by a heavily regionalized dermis that likely increases surface area during prey manipulation to increase grip. In contrast, the lips of carnivorous piranhas are interspersed with loose connective tissue and fat, with no regionalization of tissues. Lips of grazing and fruit-eating pacus are both passive but the arrangement of collagen and connective tissues will affect the deformability of the lips and how the lips work to distribute stresses while stretching to handle prey.

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How does kangaroo rat locomotion respond to changes in terrain manipulations during foraging in the field?

Behavior and morphology are adaptations to foraging in physically demanding and risky habitats. At the crux of behavior and morphology, locomotion is an adaptation that hypothetically facilitates niche partitioning and competition in vertebrate communities. And how fast an animal chooses to move has physiological and ecological consequences. We investigate speed choice and locomotor behavior of kangaroo rats (*Dipodomys nelsoni* n=10, *D. merriami* n=10) under varying risk manipulations at the Mapimí Biosphere Reserve, Durango, México. Specifically, we test the hypothesis that changes in terrain will increase perceived foraging risk, thereby altering behavior. Second, we predicted that a waning moon will decrease the perceived risk. Locomotion and behavior were measured from video recordings (30 Hz) as individuals foraged under semi-natural conditions. We used rocks representative of nearby habitats to manipulate terrain. We chose these rocks because they delineate *D. nelsoni* habitat. Individuals of this species are denizens of flat, sandy areas. Preliminary data suggest kangaroo rats do not alter their locomotor behavior or speed relative to moonlight. Observations include a reluctance to approach manipulated substrate conditions by *D. nelsoni*, but not *D. merriami*. Accelerations, turns, and jumps were observed during interspecific competitions. Speeds were as high as 6 ms^{-1} during interspecific chases but were slower (~3 ms^{-1}) during baseline activity. We discuss our results in the context of bipedal hopping, habitat use, and mechanisms of species coexistence. Sponsored by a Company of Biologists Travelling Fellowship 180221 to CEC.

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Does ultraviolet light influence thermoregulation behavior in lizards?

Diurnal lizards often shuttle between exposed sunlit and shaded areas of their habitat, a behavior classically (and often solely) treated as a primary mechanism for thermoregulation. However, this behavior also affects exposure to other wavelengths of light important for fitness. For example, ultraviolet (UV) exposure stimulates endogenous production of vitamin D3 that is essential for calcium absorption, muscle function, and bone development, among other functions. Thus, both UV and thermal needs may drive

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behavior often attributed to thermoregulation alone. Despite these considerations, data on the effects of UV light on lizard behavior, including how UV needs may interact with (or override) thermal needs, are limited. Here, we capitalize on a laboratory environmental gradient approach to take an important step towards unraveling how variation in temperature, UV, and their interaction affect lizard behavior. We evaluated the behavior of 40 adult fence lizards (*Sceloporus undulatus*) in a laboratory environmental gradient with respect to four treatments: a temperature gradient alone, a UV gradient alone, a matched gradient of temperature and UV [gradients occur in the same direction], and an unmatched gradient of temperature and UV [gradients occur in opposite directions]. Depending on the treatment, we continuously recorded lizard body temperature (OMEGA logger) and/or UV exposure (UV Index, Arduino-based logger) for a 60-minute period per trial. Currently, our experiment is ongoing, but nearly completed. We expect our findings to provide novel insight into whether lizards regulate UV exposure and how that exposure influences their thermoregulation decisions. Our findings should also improve our ability to interpret apparent thermoregulation behavior by reptiles in both the lab and field.

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Striped mullet die-off after heatwave in Malibu Lagoon, Los Angeles

In Southern California, as climate and anthropogenic changes continue to alter coastal systems, fish die-offs are seemingly becoming a more regular occurrence in lagoons. These are likely caused by urbanization, but also by restoration efforts that can have undesired effects on several local biotas. Understanding how these different factors impact coastal lagoons and promote fish die-offs is relevant to inform conservation practices. In August of 2018, Malibu Lagoon, which went through two phases of restoration (1983 and 2013), had a massive die-off event of striped mullet, *Mugil cephalus*. However, the exact environmental process that induced this event is unknown. Hypoxia is the most likely cause of the die-off based on the geologic and atmospheric evidence. The die-off occurred during a heatwave, leaving the

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lagoon at an average of 27° C, this led to a decrease of dissolved oxygen in the water. At the same time, there was an increase in cloud coverage, decreasing the production of dissolved oxygen by fauna. The low dissolved oxygen level as well as the high abundance of fish and high temperatures would have caused an extensive amount of stress on the fish, quickly leading to their demise. Although, this event could have had multiple other stressors. To further our understanding, we will be analyzing Environmental DNA samples from before, during, and after the die-off. These sediment and water samples will be tested fo the presence or absence of toxic algae, disease, or other species that could be related to the die-off. As well as bacteria present for specific biochemical cycling during the die-off. Conclusions from this study will convey how the geologic processes of lagoons have and will be altered, as well as how these alterations have impacted the species within them.

P20-7 Coughlan, K*; Sadowska, ET; Bauchinger, U; Institute of Environmental Sciences, Jagiellonian University, Krakow, Poland, Institute of Environmental Sciences, Jagiellonian University, Krakow, Poland and Nencki Institute of Experimental Biology PAS, Poland; *kyle.coughlan@doctoral.uj.edu.pl*

Decline in haematocrit with increasing age in zebra finch (Taeniopygia guttata)

Senescence, or ageing, has been defined as a persistent decline in the age-specific fitness components of an organism due to internal physiological deterioration. Whole organismal declines in metabolic performance are known to occur due to ageing in avian species, as well as mammals. However, the causes for this decline in aerobic metabolism and performance are not well understood. Supply and removal of respiratory gases are key to aerobic metabolism and erythrocytes take a central role. In mammals, including humans, haemoglobin concentration, red blood cell count, and haematocrit begin to decrease in later life. In birds however, such knowledge on changes in haematological variables with increasing age is still lacking or data provide even contradictory results. We tested if haematological variables decline with increasing age in a passerine bird, the zebra finch (*Taeniopygia guttata*). Forty-five males aged 15 to 84 months were sampled for haematocrit, haemoglobin content, red blood cell size and number against age as a continuous factor.

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We found a statistically significant decline in haematocrit due to ageing in the birds (P<0.029) and a weak but not significant decline in haemoglobin, while the red blood cell size and number remained constant. The age dependence of haematological variables appears less clear in birds than in mammals. Besides oxygen carrying capacity, haematocrit influences the viscoelastic properties of blood and it remains to be shown if this decline in haematocrit in birds can explain declining aerobic metabolism.

P15-3 Coutts, VM*; Beatty, A; Schwartz, T; Cooper, C; Hurley, L; Griffith, S; Wada, H; Auburn University, Auburn, AL, Macquarie University, Sydney, NSW, AUS; *vzc0035@auburn.edu*

Differential gene expression of anti-damage regulators at the upper limit of the thermoneutral zone in zebra finches

Thermal physiology contributes to limits on heat tolerance and species' geographical distribution. Small birds living in the desert is particularly at risk of heat stress because of heat waves, diurnality, and limited access to food and water. Using zebra finches (*Taeniopygia guttata*) as a model system, we tested whether temperatures at the upper limit of the thermoneutral zone would elicit anti-damage regulators to minimize cellular damage caused by heat. To test this, blood samples from birds were collected both in the field and lab. Laboratory birds were placed in two treatments: 1) 30° C for 8 hours and 18° C for the rest of the day, and 2) 40° C for 8 hours and 28° C for the rest of the day. These treatments occurred for 2 weeks, then all birds went through a period of the cooler temperatures (18° C or 28° C) for 2 weeks. After that, they were exposed to the higher temperatures (30° C or 40° C) again for 8 hours. Whole blood was collected from these individuals after the last heat exposure. Blood samples from field birds were collected during Cool temperatures (three or more days of maximum T_a less than or equal to 36° C) or Hot temperatures (three or more days of maximum T_a greater than or equal to 39° C). Currently, we are quantifying differential gene expression of heat shock protein (HSP) 60, HSP70, HSP90, interleukin 1 beta (IL1B), and APTX (mitochondrial DNA repair gene) in field samples and HSP70, HSP90, and IL1B in lab samples with the prediction that these genes will be elevated in the zebra finches exposed to 40° C in the lab or Hot temperatures in the field.

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P24-7 Couvillion, KE*; Kelly, TR; Lattin, CR; Louisiana State University; *kcouvi8@lsu.edu*

Effects of experimental malaria infection on self-maintenance behavior in house sparrows

Climate change is expected to intensify the transmission rate of avian malaria, threatening future populations and biodiversity of songbirds worldwide. The relationship between infection status and behavior currently relies heavily upon observational studies, so it is difficult to predict the extent to which increased *Plasmodium* incidence may affect songbird behaviors required for food acquisition and self-maintenance. In this experiment, we inoculated wild-caught house sparrows (*Passer domesticus*) with either a naturally occurring malaria species (*Plasmodium*) or a "sham" control inoculation (donor blood not infected with *Plasmodium*). Behavior was quantified from 90 min video recordings of sparrows, after a 30 min habituation period, on day -5 (5 days before inoculation) and days 2, 6, 9, and 13 days post-inoculation. Observers were blind to bird treatment (infected n=9, resisted infection n=5, sham n=6). We quantified activity (number of flights and hops), feeding duration, and preening duration of all individuals. We predicted that only the successfully infected birds would show decreased behavior in all three categories. Preliminary data from pre-inoculated and day 2 post-inoculation videos demonstrated that successfully infected house sparrows exhibited no change in general activity levels, increased overall time spent preening, and decreased time spent feeding as the experiment progressed (in contrast to controls). We detected no behavioral changes in exposed-but-uninfected (resistant) birds. These results suggest that successful malaria infection may affect feeding and self-maintenance behavior mere days after malaria exposure.

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New morphometric and structural descriptions of the Florida manatee spermatozoon

Sperm morphometry and structure provide useful information regarding the reproductive physiology of a species, which is especially important for marine mammals where information on the spermatozoon is limited. In this study, we investigated the morphometry and structure of the Florida manatee (*T. manatus latirostris*) spermatozoon. Sperm were retrieved postmortem from the vas deferens of nine adult males classified as "fresh" at necropsy (<24 hr postmortem). Samples were analyzed by automated sperm morphometry analysis (ASMA), laser-scanning confocal microscopy (LCSM), and electron microscopy to assess morphometry and structure, respectively. Morphometric parameters analyzed in this study were approximately 1.5-2 times larger than those previously reported for the Florida manatee. Structurally, sperm had strong localization of F-actin along the midpiece, the axoneme contained four enlarged outer dense fibers (1,5,6, and 9), and midpiece volume was similar to other species that exhibit a multi-partner mating system. Combined, these features may highlight how sexual selective pressures have shaped sirenian sperm morphology and may provide further evidence for the possible occurrence of sperm competition in this species. This is the first study to provide extensive morphometric and structural analysis of the Florida manatee spermatozoon and the results continue to add to the increasing information on male reproductive physiology, which is critical for effective management and conservation of this threatened marine mammal species.

P5-7 Crow, RS*; Dethier, M; Wyllie-Echeverria, S; University of Virginia, Charlottesville, Virginia, Friday Harbor Laboratories, University of Washington, Friday Harbor, WA; *rsc4vf@virginia.edu*

Experimental evaluation of Abarenicola pacifica burrowing behavior: implication for Zostera marina restoration and expansion success using seeds

Seed dispersal and burial are important processes in the expansion and restoration of *Zostera marina* (eelgrass). The depths at which seeds are buried are a significant factor contributing to seedling survival. If seeds are buried below 6 cm, it is unlikely that

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viable seedlings will develop. Burrowing behavior of infaunal organisms can contribute to seed burial and has the potential to be a positive or negative influence on seedling survival. In this study, a mesocosm experiment tested the relationship between lugworm (*Abarenicola pacifica*) density and eelgrass seed burial. Three treatments (no worms, low-density, and high-density of worms) were used to examine seed burial. Three replicates per treatment were seeded with a blend of mimics and real seeds. After 25 days, three cores were extracted from each replicate and the depths of the seeds were recorded. In the high-density worm treatments, the majority of the seeds and mimics were found buried below the 6 cm critical depth, while in the low-density treatment most were shallower than 6 cm, with most of the seeds in the control treatments remaining at the surface. These results indicate that the density of *A. pacifica* should be investigated in order to predict the success of *Z. marina* expansion and restoration efforts.

P35-3 Cupp, PV; Eastern Kentucky University; *paul.cupp@eku.edu*

Female Aneides aeneus avoid mating with inferior males near egg deposition time

Late in the breeding season, some male green salamanders, *Aneides aeneus*, may enter rock crevices containing gravid females waiting to deposit eggs. These females appear to reject these males as egg deposition time nears. Many of these males may be satellite males that have not defended territories and thus might be considered inferior or less fit compared to males that have defended territories. By placing unfamiliar males with resident gravid females in lab and field during June and early July, most of the gravid females avoided mating with these potentially inferior males. The females would often just leave the crevice or remain in the crevice and resist the males attempt to initiate courtship. Some females became quite aggressive and chased males from the brooding crevices. Thus, it appears adaptive for gravid females to avoid mating with inferior males near egg deposition time. Females have likely previously mated with territorial males and should not mate with inferior males and dilute sperm stored in the spermatheca with sperm from inferior males. This description of gravid female *A. aeneus* rejecting less fit males may be considered as a good example of cryptic female mate choice (CFC).

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P16-1 Cyrino, JC; Figueiredo, AC; Gomes, FR; Titon, SCM*; University of Sao Paulo, Sao Paulo, Brazil; *stefannychristie@gmail.com*

Modulation of extra-pineal melatonin in response to an immune challenge with LPS in Rhinella icterica toads

Melatonin production in extra-pineal sites is modulated by pathogen-associated molecular patterns and affects immune response. We investigated melatonin production by pineal vs. extra-pineal tissues of toads (*Rhinella icterica*). The animals were intraperitoneally injected with LPS (2mg/kg) or saline at 10h and 22h. Tissues from these toads (blood, bone marrow, lungs, liver, and intestine) were sampled 2 hours after the injection (noon and midnight). Plasma and tissue homogenates melatonin levels were determined by ELISA kits. LPS treatment increased melatonin concentration in bone marrow during the day, and melatonin levels in the bone marrow were higher during the day than at night in the LPS group. Melatonin concentration in the liver showed a tendency for higher concentration in the LPS than in the saline-injected toads during the night. Melatonin levels in the intestine were also higher at night than during the day. Plasma melatonin levels and lung melatonin concentration were not affected either by the treatment or the period. Our results showed that melatonin is present in extra-pineal tissues in R. icterica toads, and its concentration is modulated in different tissues by an immune challenge. Moreover, the period of increased melatonin production in response to LPS differs between tissues, evidencing the complexity of individual defense against pathogens.

P37-5 Daigle, KR*; Webb, JF; Maia, A; Rhode Island College, Providence, RI, University of Rhode Island, Kingston, RI; *kdaigle_3723@email.ric.edu*

The role of ultraviolet light on mating behavior in two sand dwelling Lake Malawi cichlid fishes

Ultraviolet light is present in the underwater light field and varies with turbidity, depth, and time of day. Previous research has indicated the importance of ultraviolet light in the behavior of various vertebrates, including fishes. We investigated the role

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of ultraviolet light (UV) on the mating behaviors of two Lake Malawi cichlids, *Aulonocara stuartgranti* and *Tramitichromis* sp., sand-dwelling (non-mbuna) species. We tested the hypothesis that UV reflective components of body coloration serve as stimuli during mating behavior. Experiments were designed to determine how males respond to a female under varying light conditions - full spectrum (400-700nm) or ultraviolet light A (380-400nm), which enhances UV reflectivity of body coloration. Individual male fish (*A. stuartgranti*, n=3; *Tramitichromis* sp., n=5) were acclimated in an experimental tank for five minutes before the introduction of a female. Mating behaviors (fin display, chasing, tank patrol) were recorded in 30 minute trials using HD digital video under either visible spectrum or ultraviolet light (3 trials per fish). Behaviors were analyzed with respect to frequency and duration. Males of both species displayed mating behaviors more frequently under ultraviolet light than under full spectrum light. This provides evidence for UV vision and the importance of UV reflective components of body coloration in the mating behavior of these fishes. This research has been partially funded by RI C-AIM (NSF EPSCoR).

P36-2 Dang, A*; Bernard, GD; Olguin, AR; Macias-Muñoz, A; Lawrence, JP; Hill, RI; Mullen, SP; Briscoe, AD; University of California, Irvine, University of Washington, Seattle, Universidad Nacional Autónoma de México and University of California, Irvine, University of the Pacific, Boston University; *danga5@uci.edu*

Color vision in the nymphalid butterfly, Adelpha fessonia

Mimicry is a defensive strategy that helps prey avoid predation by resembling unprofitable species. Due to the prevalence of mimicry in many butterfly genera, visual discrimination is especially important in identifying conspecifics for reproduction. We investigate the visual system of *Adelpha fessonia*, a nymphalid butterfly belonging to a diverse genus that possesses multiple mimicry complexes. Using eyeshine, epi-microspectrophotometry, optophysiology, spectroscopy and RNA-Seq data, we found no evidence of red-green color vision in *A. fessonia* as their eyes do not have the necessary two long-wavelength-sensitive opsins or filtering pigments. We quantified the expression levels of the mRNAs of visual opsins along with other opsin-like proteins to determine

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their level of involvement in vision. With transcript per million assays, we found that the ultraviolet, blue, long-wave, and unclassified opsins were highly expressed in *A. fessonia* head tissue while RGR-like opsin and pteropsin were not. The distribution and abundance of the blue-absorbing opsin across the *A. fessonia* compound eye were examined using immunohistochemistry. Phylogenetic trees consisting of various *Adelpha* species were created from opsin alignments and tests for positive selection for each protein were performed. Our results reveal characteristics of *A. fessonia* eyes which can be compared to other *Adelpha* and nymphalid species. Examining visual systems of individual *Adelpha* species is integral to understanding how color vision has diversified over time in mimetic species.

P14-1 Das, N*; Josephson, B; Murray, K; Stockton University, National Oceanic and Atmospheric Administration; *dasn@go.stockton.edu*
Evaluating automated image analysis for pinniped assessments
Aerial photographic surveys have long been used to monitor gray and harbor seal populations, but extracting data from those images is a time-intensive process. Just one image from a haul-out or pupping site may contain over one hundred seals, which must be manually counted and categorized by sex or age. This project aimed to automate this image analysis and obtain population estimates more efficiently through machine learning, specifically with the software VIAME (Video and Image Analytics for Marine Environments). Survey images from gray seal pupping sites on Monomoy and Muskeget Islands off of Cape Cod, Massachusetts were manually annotated to identify pups and adults, after which the annotations were used to generate a trained detector through deep learning. After 4 iterations of this process, the detector's probability of correctly identifying a pup or adult of this species on sandy substrates is 0.87. Going forward, this detector will be further refined to provide accurate estimates of gray and harbor seal abundance in various environments in a fraction of the time it would take using traditional methods.

P12-5 Dawkins, CD*; Kruppert, SK; Donatelli , CD; Crofts, SC;

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Kolmann, MAK; Cornell University; *jsd99@cornell.edu*
Comparing apples to oranges: Tooth performance of frugivorous piranhas and pacus (Serrasalmidae)
Frugivores, animals that consume fruits and seeds, play an essential role in growing and maintaining plant communities by dispersing the seeds contained in a frugivore's excrement. Many Amazon rainforest trees rely on seasonal flooding and frugivorous fishes like piranhas and pacus (Serrasalmidae) to disperse fruits and seeds across vast distances. We compared tooth puncture performance among three serrasalmid species with varying tooth morphologies: (1)*Piaractus brachypomus*, a large herbivorous pacu; (2) *Pristobrycon maculipinnis*, an odd frugivorous piranha; and (3) *Megapiranha paranensis*, an extinct serrasalmid considered to be the sister taxon to all extant piranhas. We compared the force and work it takes for 3D printed tooth models, obtained from microCT scans, to puncture different fruits. We predicted that the blunter pacu tooth would require the most force to puncture fruit, emphasizing how broader contact areas produce greater damage to fruit cells, as documented for bats and primates. Megapiranha teeth behaved more like pacu teeth for softer oranges; however, for stiffer apples, pacu and piranha teeth had similar puncture mechanics. Pacu and Megapiranha teeth produced higher forces and work when biting stiffer fruit, as predicted. However, tooth performance was similar among serrasalmids when indenting softer fruit. Across all performance measures, Megapiranha tooth performance did not resemble that of piranhas, which parallels ancestral state reconstruction findings that piranha ancestors were herbivorous. However, piranha teeth performed similarly to pacus during initial puncture and were similar overall when processing softer fruit, only differing once teeth were fully indented in stiffer fruit. Our findings demonstrate functional diversity within frugivorous fishes, and broadly suggest that serrasalmids have functionally versatile dentitions.

P38-2 De León, A*; Madrid, M; Collin, R; Smithsonian Tropical Research Institute, Panama and the International Maritime University of Panama, Smithsonian Tropical Research Institute, Panama; *alexdl609@gmail.com*

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Diversity of holoplanktonic gastropods during seasonal upwelling in the bay of Panama

Seasonal upwelling in the Bay of Panama and along the Pacific coast of Panama in general occurs during the dry season, from January to April. This event leads a reduced water temperatures and high marine productivity. This is the first study of holoplanktonic gastropods from the *Pteropoda* and *Pterotracheoidea* in Panama. Holoplanktonic gastropods are mollusks that have managed to develop their complete life cycle in the pelagic zone. These gastropods are known for being potentially good indicators of ocean acidification, as they are highly sensitive to environmental conditions, yet their abundance and distribution in coastal waters are poorly known. Here we documented their diversity and abundance from weekly vertical plankton tows taken during upwelling and non-upwelling seasons at three different sites in the Bay of Panama. Environmental data was collected during the weekly sampling. Gastropods were separated from the samples, counted and identified using morphological criteria based on the general shell morphology, the count of spires and type of eye present. A total of 15,153 organisms were collected from the three sites and belonged to the genera *Atlanta*, *Firoloida* and *Pterotrachea* from the *Pterotracheoidea* and the genera *Cavolinia*, *Creseis*, *Paraclione*, *Clio*, *Corolla*, *Diacavolinia*, *Diacria*, *Hyalocylis* and *Limacina* from the *Pteropoda*. The *Pterotracheoid* genera were equally abundant all year, but the pteropods were generally significantly more abundant during non-upwelling. Overall pteropod abundances were positively correlated with water temperature, dissolved oxygen concentration and pH and negatively correlated with salinity, which reflects the seasonal changes in seawater characteristics.

P35-6 Dees, AG*; Wilson, K; Reali, C; Preutt, JE; Hall, JM; Brandt, R; Warner, DA; Auburn University, University of Alabama at Huntsville, Science North, Sudbury ON; *agd0022@auburn.edu*

Communal egg-laying behavior and the consequences of egg aggregation in the brown anole (Anolis sagrei)

Communal nesting may be a consequence of a shortage of preferable nest sites (constraint hypothesis) or an adaptation generated by fitness benefits associated with egg aggregation (adaptive

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hypothesis). To test these hypotheses, we studied a lizard (*Anolis sagrei*) that often aggregates eggs in nest sites. In a lab study, females were given the option of nesting in (a) soil previously used as nest substrate vs. fresh soil and (b) soil with eggshells vs. without eggshells. We also experimentally examined the effects of egg aggregation by incubating eggs singly, in groups of four, and in groups of nine. Females were more likely to nest in pots with used soil and with eggshells than in pots with fresh soil or without eggshells. We observed no effects of egg aggregation on egg survival, egg temperature, or most measures of hatchling morphology. However, singly-incubated eggs absorbed more water than eggs incubated in the four and nine egg aggregations and this resulted in offspring with greater body condition at hatching. The behavioral experiment demonstrates that females actively choose nest sites that have been used previously (as expected under the adaptive hypothesis), but the egg aggregation experiment shows no benefits to offspring based on the variables measured. Thus, results of the behavior study support the adaptive hypothesis; however, results from our egg-incubation study do not. Likely, the adaptive and constraint hypotheses are not mutually exclusive, and a diversity of factors influence the evolution of communal nesting behavior.

P13-1 DeLorenzo, L*; Powder, KE; Clemson University; *ldelore@g.clemson.edu*

Epigenetics and the evolution of form

There is growing evidence that non-genetic factors play an important role in animal diversification, from horn variation in beetles to eye loss in cavefish. "Epigenetics" describes modifications that alter DNA packaging, chromatin structure and thus gene expression. To investigate the role of epigenetic factors in species-specific diversification, we used Lake Malawi cichlids. These fishes underwent a textbook adaptive radiation and a hallmark of this is diverse craniofacial morphologies that define feeding mechanisms along a pelagic/benthic axis. To assess the phenotypic effect of altered epigenetic regulation, we inhibited histone deacetylation (HDACs) using the drug Trichostatin A (TSA) during specific windows of facial development in both zebrafish and three Malawi cichlid species with distinct adult morphologies (*Tropheops*

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sp. and *Maylandia sp.*). Results were quantified using geometric morphometric shape analysis. In both zebrafish and cichlids, we found that during neural crest cell migration, treatment with TSA significantly altered facial shape resulting in an overall wider Meckel's cartilage, wider branchial structures and an overall shorter head (ZF: p=0.03 vs. controls; *T.ch.*: p=<0.001 vs. controls). In cichlids, there were species-specific effects in induced phenotypic variation. This may suggest that the regulation of HDACs is robust, but there may be other molecular architecture that influence phenotypic divergence and that some species may be more "evolvable" than others. TSA treatment during later timepoints showed no significant changes to craniofacial morphology in zebrafish or cichlids. This work shows that neural crest cell migration is a sensitive interval for HDACs to impact "normal" craniofacial development both in zebrafish and in cichlids. Epigenetic mechanisms may have a widespread role in morphological diversification across vertebrates.

P41-7 Di Stefano, NE*; McGowan, CP; Lin, DC; Washington State University, University of Idaho; *norberto.distefano@wsu.edu*

The plantaris muscle substantially increases stiffness of the metatarsal phalangeal joint in kangaroo rats

Terrestrial animals coordinate the elastic properties of their limb joints during locomotion by activating specific muscles at specific times. During bipedal hopping by kangaroo rats, the metatarsal phalangeal (MTP) joint in the foot must be compliant during the landing phase to accommodate surface variations. In the process of transitioning from landing to takeoff, the MTP joint must become stiff to produce the ground reaction forces needed for propulsion. The objective of this research is to elucidate the mechanisms by which the MTP can transition from compliant to stiff in kangaroo rats. We hypothesize that this transition can be produced by the activation of the digital flexor (DF) muscle and of the plantaris (PL) muscle, which is often considered solely as an ankle plantarflexor. Furthermore, we hypothesize that limb posture will affect how quickly muscles are able to change the MTP stiffness upon activation due to slack in the muscle tendons in more plantarflexed positions. To test these hypotheses, we estimated MTP stiffness of anesthetized kangaroo rats by rotating their MTP joint

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and measuring MTP moment while activating the DF and PL separately. Preliminary analysis shows ~50% of maximal activation of the PL and DF resulted in an MTP stiffness of 0.056 N-cm/deg and 0.057 N-cm/deg, respectively, which indicates that both muscles can contribute substantially to MTP stiffness. In the more plantarflexed limb posture tested, isometric activation of the PL (starting from a passive state) took 25% more time to generate 60% of the maximal joint moment compared to the more dorsiflexed posture tested, a result that indicates more tendon slack in the plantarflexed posture. Both results are important for understanding how different muscles and postures can modulate MTP stiffness during locomotion.

P10-8 Diamond, KM*; Avants, BB; Maga, AM; Seattle Children's Research Institute, University of Pennsylvania; *kelly.diamond@seattlechildrens.org*

Machine learning-based segmentation and landmarking of 2D fish images

As museum collections are digitized, specimen images provide potential dataset for new research questions. However, preprocessing and data collection from these images is often a time-limiting step. With advances in machine learning (ML) techniques we can make better use of publicly available data by extracting useful measurements in a fraction of time it takes to measure images individually. In this project our goal is to develop ML pipelines to isolate, landmark, and segment a large number (14,000) of 2D fish pictures from digital museum collections. As a preprocessing step, we isolated fish from museum images that contained other non-fish objects. Using fewer than 100 images as a training set, we had over 95% success in isolating fish from over 14,000 images, representing 118 species. Next, we took a sample of 500 of these images and manually placed 24 landmarks and created segmentations of anatomical portions of the fish's body. We are working on using these segmented and landmarked images to train a new ML model to automatically place landmarks and segment unseen images. We will review and revise the outputs from this pipeline and then rebuild the ML model. This iterative process, known as active learning, is more time-effective to generate the large amount of training data necessary for successful ML models as well

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as enabling faster image processing from open source datasets. All of these tasks are accomplished using the open-source software: Advance Normalization in R (ANTsR) for model building and computational tasks, and SlicerMorph for segmentation and interactive landmark data acquisition. Our experiments shows that ML holds the key unlocking large biodiversity data available in specimen collections for organismal biology research.

P28-2 Dohr, SR*; Tuffield, MS; Hahn, KM; Ward, RS; Moore, CD; Shu, Y; Morisawa, R; Derkarabetian, S; Boyer, SL; Macalester College, Harvard University; *sdohr@macalester.edu*

Phylogenetic placement of two new species of New Zealand mite harvestmen based on target-capture of ultra-conserved elements (UCEs)

We conducted species delimitation in mite harvestmen of the genus *Aoraki*, one of three genera of these tiny arachnids endemic to New Zealand, using integrative taxonomy combining morphology and genetic data. We sequenced two mitochondrial loci commonly used in species delimitation, and also used target-capture of ultraconserved elements (UCEs) to generate data for an average of 378 loci per individual from a subset of our specimens. We imaged individual animals using scanning electron microscopy (SEM), and made anatomical comparisons with described species. We identified two novel species based on unique features of the anal plate and fourth tarsus of male individuals. Phylogenetic analysis of mitochondrial DNA confirmed monophyly of each new species; a phylogeny based on preliminary UCE data confirms that each new species is most closely related to a geographically adjacent species. Although it is believed that most of the diversity of *Aoraki* is known, questions remain regarding species delimitation within the genus. The UCE approach we have piloted has great potential to resolve species limits in this group prone to cryptic speciation.

P10-2 Dolkas, GA*; Wimberger, PH; University of Puget Sound; *alexdolkas@gmail.com*

Barb density measures often compound barb density and barb angle

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Feathers are crucial to survival and reproduction in birds, functioning in insulation, flight, camouflage, and communication. As with most biological structures, form affects function, and the structural properties of feathers affects their performance. One oft-used measure of feather structure is barb density (Bachmann *et al.* 2007), the number of barbs per unit measure, typically measured at the midpoint of the feather along the rachis. This measure has been used by multiple researchers to characterize structure of the feather and as a means of comparison between species. We will show how the traditional methodology is misleading because it compounds barb density with barb angle, two independent features of feather morphology. Conclusions inferred from the traditional measure are, at best, imprecise, and at worst, wrong. We suggest that both barb angle and barb density measured perpendicular to the barbs be reported and propose an alternative approach in which barb angle is used to compute barb density.

P19-7 Doucet, DS*; Herrera-Martínez, A; Campbell, TL; Daza, JD; Sam Houston State University, Texas Invasive Species Institute, SHSU, Baylor University; *dsd020@shsu.edu*

Osteological differences among populations of the Puerto Rico bush anole (Anolis pulchellus)

The Puerto Rico bush anole, *Anolis pulchellus*, is very widespread species in the island of Puerto Rico and the Virgin Islands (except St. Croix). Previous studies (morphological and molecular) indicate that this species exhibit considerable variation among populations. This research is a follow up of an unpublished data set based on external morphology. Here we measured 8 cranial and postcranial variables using digital x-rays of 35 specimens across the distributional range of the species. Digital x-rays were obtained using a Thermo Scientific™ PXS5-927 Micro Focus 90kV X-Ray Source and Amorphous Silicon Digital X-Ray Detector, and linear measurements were gathered using ImageJ. Linear measurements were first log transformed, size was calculated as the geometric mean (GM) and shape variables were produced (as scaled proportions) by dividing log distances by the GM. Newly generated shape variables were then subjected to a PCA to explore the influence of each variable on the total variance explained. Additionally, resulting PC scores were then used in a MANOVA to test for differences in

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shape between mainland and island populations. Results from our analysis showed that these populations do indeed separate using the variables selected (Λ =0.1206; P< 0.001). Using the linear measurements, we found marked differences between the Puerto Rico and the Virgin Islands. This is a preliminary analysis, and we plan on combining this data set with data from the integument. Cranial scale counts, lamellae counts, and skeletal measurements have the potential to add more resolution to the morphological differences between populations of *Anolis pulchellus*.

P6-6 Douglas, HD*; Ermakov, I; Gellermann, W; University of Alaska Fairbanks, and Grambling State University, University of Utah, Salt Lake City; *douglashe@gram.edu*

Unique fluorochrome increases social attraction in crested auklets (Aethia cristatella) and reveals a link to ecology

Brilliant orange bills are a striking contrast to the sooty gray plumage of the crested auklet (*Aethia cristatella*), a colonial seabird of Alaska and Siberia. We characterized this pigment with three spectroscopy techniques. With Raman Resonance Spectroscopy we identified a fluorescence peak at ~527 nm (similar to YFP-10C). Using fluorescence spectroscopy (FS) we found the fluorochrome is unique in the Genus Aethia, but we also found phenotypic differences. Our samples from St. Lawrence I., AK were all single-band fluorescence (n=11), while Little Diomede I. (LD) included single and two-band phenotypes (n=10). Crest size, a signal of dominance, correlated with highest fluorescence in the single-band phenotype ($r_{s\ 1\text{-tailed}} = 0.48$, p=0.04, n=14). The fluorochrome has absorbance spectra similar to known pterin compounds (6-biopterin, pterine, pterin-6-carboxylic acid). Interestingly, euphausiids, a favored food of crested auklets, overlapped in their absorbance spectra with the fluorochrome. We assayed for an effect on behavior of using decoys that differed only in bill fluorescence. Crested auklets approached the models with fluorescent bills at a higher frequency ($t_{(34)} = 2.78$, $p_{1\text{-tailed}} = 0.004$). We suggest that a preference for the fluorochrome could have evolved by exploiting a preexisting bias in crested auklet visual systems, linked to a prey preference. The possibility that bill color may advertise foraging ability was supported when in the marine heat wave of 2016, 11% of crested auklets captured at LD had incomplete bill pigmentation.

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P13-5 Drake, PM*; Franz-Odendaal, TA; Dalhousie University, Halifax, NS, Mount Saint Vincent University, Halifax, NS; *paige.drake@dal.ca*

Masters of versatility: Placode development in an emerging experimental model, the chicken scleral ossicle system

The hair on your head, feathers of a bird, scutes of a turtle shell, scales of a lizard, and lens of an eye. What do these structures all have in common? Despite striking differences in appearance and function, they all began as placodes. That is, localized thickenings of the epithelium that give rise to two main groups of derivative structures: cranial placodes (e.g. lens, lateral line, trigeminal ganglion) and cutaneous placodes (e.g. scales, feathers, hair). These regions of thickened epithelium are hubs of communication between the epithelium and mesenchyme that induce of a wide range of specialized neurogenic and epithelial appendages. They are sites of coordinated changes in cell proliferation, differentiation, shape, and movement. They have also been studied in terms of inductive signaling networks (e.g. Wnt/β-catenin, FGF, BMP, Hh, Eda/Edar), epithelial patterning mechanisms (e.g. lateral inhibition), and extracellular matrix regulation (including matrix metalloproteinases). Like other cutaneous placodes, scleral ossicle bones begin with a placode stage. In the conjunctiva of the eye, thickening of the epithelium forms an elongated papilla that instructs skeletogenic condensations to form in the underlying mesenchyme, which ultimately give rise to scleral ossicle bones. Such bones form intramembranously in the eyes of several vertebrate groups. In the chicken (*Gallus gallus*) eye, the ability to knock out one or more of these placodes via chemical treatment presents a unique opportunity to learn more about placode patterning. Investigating early induction of scleral ossicles can reveal more about this curious system of bones, as well as the versatility that placodes harness to produce such a wealth of epithelial derivatives.

P28-7 Drummond, MS*; Colburn, NR; Ellis , EA; Gerrish, GA; Oakley, TH; Goodheart , JA; University of California, Santa Barbara, University of Florida, Center of Limnology; West Lake Station,

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A new species of bioluminescent ostracod from the reefs of Carrie Bow Caye, Belize (Ostracoda: Myodocopida: Cypridinidae)

Ostracods are a group of small crustaceans found abundantly across freshwater and marine habitats. Within the family Cypridinidae, males of many species found exclusively in the Caribbean evolved to produce magnificent bioluminescent courtship displays. During courtship displays, males swim helically in the water column and emit pulses of bioluminescence in a variety of species-specific patterns. The species-specific nature of these displays may have led to an increase in diversification rates, since clades from multiple groups that use bioluminescent signaling consistently have more species than non-displaying sister groups. Due to such high levels of diversity, putative new species are collected frequently by targeting unique display patterns. During a field expedition to Belize, we captured a previously undescribed species of cypridinid ostracod with a downward angled display that could not be easily matched to any previously described species, and was even difficult to place within a genus. Here, we present a species description for this population of ostracods. By identifying distinguishing morphological features using compound microscopy and confocal imaging, as well as transcriptome-based phylogenetic methods, we establish this group of ostracods as a new species in Cypridinidae within the genus Maristella.

P41-8 Duman, A*; Azizi, E; University of California, Irvine; *aduman@uci.edu*

Role of hindlimb proprioceptive feedback in the coordinated landing behavior of Rhinella marina

Variation in surface conditions during locomotion can cause animals to alter their behavior in order to effectively navigate complex terrain. The cane toad, *Rhinella marina*, has become a model organism for exploring the biomechanics of controlled deceleration because of its ability to hop repeatedly and exercise its forelimbs to dissipate energy upon impact. However, it remains unclear how these animals respond to natural variation in surface conditions while locomoting. Previous work suggests cane toads may not rely on sensory feedback from forelimbs to alter muscle activation when landing on compliant surfaces, while others have shown that

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denervation of the hindlimbs elicits inadequate preparatory behavior in the forelimbs prior to landing. Therefore, we hypothesized that cane toads rely on hindlimb proprioception during takeoff to alter the preparatory and landing behavior. To test this hypothesis, we varied the compliance of a jumping platform in order to alter hindlimb muscle dynamics and the proprioceptive signals used to inform landing strategies. We quantified 3D kinematics during take-off and landing in toads (N = 8) across a range of take-off conditions. Our preliminary results suggest proprioceptive feedback from hindlimbs during takeoff does not alter impact kinetics or forelimb extension upon touchdown suggesting hindlimb feedback is not crucial for coordinating landing behavior. This study will complement ongoing reinnervation experiments that ablate the stretch reflex in the hindlimb muscles distal to the knee in order to more directly determine how afferent pathways inform control strategies during landing.

P24-4 Eleftheriou, A*; Luis, AD; University of Montana, Missoula; *andreas.eleftheriou@umontana.edu*

Interspecific competition differentially influences disease dynamics via competing mechanisms in a directly transmitted disease system

The dilution effect hypothesis posits that as species diversity decreases, infectious disease risk increases. Mechanisms behind diversity-disease relationships have been largely studied with vector borne and indirectly transmitted disease systems but less so with directly transmitted systems. The North American deermouse (*Peromyscus maniculatus*)-Sin Nombre hantavirus (SNV) system is an example of a directly transmitted disease system. In grasslands of western Montana, deermice compete with dominant voles (*Microtus* spp.) in species-poor small mammal communities. Empirical studies suggest that voles may influence SNV prevalence through effects on deermouse density, behavior or stress physiology. Therefore, our objective was to theoretically examine how vole density, instead of diversity *per se*, may impact SNV prevalence via competing effects on deermouse density, intraspecific contact rates and stress physiology. Using a previously validated epidemiological deermouse-SNV model, we explored various strengths of interspecific competition and stress under neutral, negative or positive

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relationships between deermouse contact rates and vole density. For a fixed range of vole densities, we found either a sole increase, a sole decrease, or a hump-shaped relationship (i.e. both increase and decrease) in SNV prevalence. A sole increase was observed only at lower competition strengths under neutral or positive relationships between contact rates and vole density. Our findings suggest that a hump-shaped relationship between competitor density and disease prevalence is theoretically possible across similar disease systems as a result of competing diversity-disease mechanisms.

P24-1 Eley, M*; Gatzke, T; Eastburn, M; Princeton High School, Princeton, NJ; *meley.1303@gmail.com*

The role of social interactions in iridovirus transmission among terrestrial Isopoda

Viruses of the family *Iridoviridae* are known to cause mass mortality in populations of ecologically and economically important vertebrates and invertebrates, although their methods of transmission are not well understood. Terrestrial isopod species such as *Armadillidium vulgare*, *Porcellio scaber*, and *Porcellio laevis* are ideal for studying iridoviruses because they turn bright purple or blue when infected. Studying these isopods' social interactions can give insights into the mechanisms that may propagate viral infection, including kinship selection, cannibalism, interspecific associations, and maternal care. Our findings also serve as a model system to explore other examples of viral transmission among and between species, such as SARS-CoV-2 and influenza strains. Viral jumps from one isopod host species to another can also inform measures that may be taken to contain worldwide pandemics, especially as iridoviruses have been implicated in deadly illnesses of fish, frogs, and turtles. Our results demonstrate all species studied strongly prefer ($p<0.01$) to be buried in the substrate as opposed to being on the substrate surface, although the species' preferences vary between the underside of a paper egg carton or within the substrate. Statistical analysis finds no significant difference between the proportions of *A. vulgare* and *P. scaber* in the various locations of their habitats, strongly indicating their populations frequently

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interact and therefore frequently create the opportunity for a viral host jump.

P30-2 Ellertson, K*; Prakash, A; Goldsmith, G; Berry, ZC; Chapman University ; *ellertso@chapman.edu*

Effects of diffuse light on the physiology, growth, and fruit yield of tomato plants

Introduction: We routinely study how the quantity of light affects rates of plant photosynthesis. However, what happens to photosynthesis when we change the angle of light? A growing body of research has demonstrated changes in leaf photosynthesis and net ecosystem exchange in diffuse light conditions caused by clouds or other aerosols. However, our understanding of the effects of diffuse light on physiological processes and the concomitant effects on growth and yield remain limited. Methods: We compared the physiology, growth and yield of tomatoes (Solanum lycopersicum) grown in direct compared to diffuse light conditions. Diffuse light conditions (ca. 50-60% diffuse) were created by a painted glass panel that leads to diffusion of light, but does not significantly reduce the quantity of light. Results: We observed significant differences in photosynthetic function, including water-use efficiency, of plants in diffuse light as compared to direct light conditions. However, there was increased leaf cupping in plants grown in direct light, which may be due to higher temperatures (ca. 3-5 ° C) in that treatment. We also observed no differences in initial plant growth (height, leaf number, and stem diameter); however, fruiting in the diffuse light conditions was higher than in direct light conditions. Discussion: Diffuse light conditions may have their greatest impact on plant structure and function by increasing flowering and fruit production. This effect may be mediated not by the light quality, but in this case by the temperature change induced by diffusing the light. As the climate warms, these results suggest that simple modifications to greenhouse structure may benefit fruit yield for key crops.

P27-7 Emmi, A*; Schuerman, D; Gormally, BMG; Lopes, PC; Chapman University; *gormally@chapman.edu*

Sickness behavior: What's T got to do with it?

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Sick animals can alter their behaviors dramatically by reducing activity, food and water intake, and social interactions. Certain species, however, are able to overcome these sickness behaviors when presented with advantageous opportunities, for example mating. It is hypothesized that increases in testosterone (T) during mate exposure may be the mechanism of sickness behavior suppression in these species. We tested whether male Japanese quail injected with a sickness behavior-inducing antigen (lipopolysaccharide or LPS) were able to increase T upon a gonadotropin releasing hormone (GnRH) challenge. Contrary to many other bird species, male Japanese quail decrease T when initially presented with females. We therefore also characterized sickness behaviors before and after interaction with a female, when T is expected to be naturally lower. The time males were resting was assessed by observers blinded to the treatments, and plasma T levels were quantified using ELISAs. As expected, LPS-injected birds rested for significantly longer periods of time relative to those injected with saline, demonstrating that LPS induces sickness behaviors in this species. Sickness behaviors were not changed upon the introduction of females. We found that LPS-exposed birds were unable to increase T upon a GnRH injection, in contrast to non-LPS exposed birds. T levels were not associated with sickness behaviors in any of the treatments. Combined, these results indicate that, in Japanese quail, an elevation of T during an immune challenge may not be possible and also that T is not associated with the severity of sickness behaviors in this species.

P5-4 Erber, JE*; George, SB; Georgia Southern University; *je04744@georgiasouthern.edu*

Lower heart rates for ribbed mussels in exposed areas of a salt marsh at Tybee Island, Georgia

Geukensia demissa, the ribbed mussel, is among many salt marsh species that are at risk of experiencing detrimental heat stress due to increasing temperatures. These mussels form large aggregates beneath patches of cordgrass (*Spartina alterniflora*) where they are less exposed to the sun's rays; however, some mussels end up in areas that lack cordgrass and experience temperatures of 36° C and above during the summer months. If mussels in exposed areas are thermally stressed, we would expect an effect on their heart rates.

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To address this possibility, we collected 40 exposed and 40 less exposed mussels from a salt marsh on Tybee Island, Georgia and measured their heart rate with CNY70 infrared sensors. We also measured body temperature of 10 exposed and 10 less exposed mussels from each of 8 large aggregates in the field. The distance between aggregates varied from 5.5 to 9 meters. We predicted that exposed mussels will exhibit higher maximum temperature tolerance and thus have lower heart rates at temperatures of 36° C. As predicted, exposed mussels had higher body temperatures (30.1 ± 1.8 ° C) and lower heart rates (53.5 ± 10.8bpm) than less exposed mussels (28.4 ± 1.0 ° C, 66.2 ± 8.5 bpm). By linking temperature and heart rate, we concluded that not all mussels will be able to deal with rising temperatures in Georgia's salt marshes. Those in exposed areas might actually be at an advantage. Decreasing their heart rate as temperature increases could be a strategy to improve energy conservation under stress.

P25-9 Faizur Rahman, MD *; Saydur Rahman, MD ; University of Texas Rio Grande Valley; *mdfaizur.rahman01@utrgv.edu*

Effects of elevated temperature on 8-hydroxy-2'-deoxyguanosine expression and DNA damage in the eastern oyster (Crassostrea virginica)

Global temperature increases due to anthropogenic activities. The effects of rising temperatures are well documented in teleost species. The Eastern oyster (*Crassostrea virginica*) is an ideal shellfish species to study global warming and oxidative DNA damage. In this study, I observed the effects of high temperature on heat shock protein-70 (HSP70), 8'-hydroxy-2'-deoxyguanosine (8-OHdG), ssDNA, dsDNA, γH2AX, a molecular marker of DNA damage, BAX, apoptosis regulator proteins, and caspase-3 (CAS); protein expressions in gills of oysters. I also analyzed extrapallial fluid (EPF) conditions in the oyster. Immunohistochemical results showed that elevated temperatures (28 and 32° C) significantly increased HSP70, 8-OHdG, dsDNA, CAS, and γH2AX protein expressions, in gills of oysters compare to control (24° C). EPF glucose level also increased; however, EPF protein concentration decreased in heat exposure oysters. Collectively, these results suggest that heat shock driven oxidative stress induces DNA damage which may lead to decreased various physiological functions in oysters.

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P9-1 Farhat, S*; Tanguy, A; Allam, B; Stony Brook University, Stony Brook, NY, Sorbonne Université, Roscoff,
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Chromosome-level assemblies of the hard clam and its parasite QPX

There is a growing interest in the use of high-throughput genotyping methods for unraveling the genomic bases of animal resilience to environmental stress or infectious diseases, particularly in non-model species. The decrease in sequencing costs made these technologies within reach, leading to an increase in the number of genomes assembled at a chromosome level, making comparative analyses between species more accurate. Here, we sequenced the complete genomes of the hard clam, *Mercenaria mercenaria*, and its parasite QPX (Quahog Parasite Unknown) responsible of severe losses in Northeastern states of the USA. Short and long-read sequencing methods were combined with the new Hi-C technology, allowing us to achieve the complete chromosomes for each species. As a result, 19 chromosomes of *M. mercenaria* were assembled for a total genome length of 1.85Gb. Around 29,000 coding genes were predicted, with the help of additional RNAseq data (92% of the genes having an assigned functional annotation). The QPX genome is 42.3Mb in length assembled into 42 scaffolds with an N50 of 1.9Mb. These findings are in line with those obtained in other members of the Labyrinthulomycota family, which are known to have a large number of chromosomes. Having high-quality genomes for both the clam and its parasite opens the door for exciting research to unravel specific genomic features in each phylum, but also on the identification of pathways involved in the host-parasite interactions that take place during infection.

P16-7 Figueiredo, AC*; Titon, SCM; Cyrino, JC; Nogueira, LAK; Gomes, FR; Department of Physiology, Institute of Biosciences, University of São Paulo, São Paulo, Institute of Environmental, Chemical and Pharmaceutical Sciences, Universidade Federal de São Paulo, campus Diadema; *aymam.figueiredo@gmail.com*

Immune and hormonal regulation in the postprandial period of Bullfrogs (Lithobates catesbeianus)

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Mammals show increased plasma and local (gastrointestinal tract) concentrations of some immunoregulatory hormones, such as corticosterone and melatonin, during the postprandial period. However, little is known about the endocrine and innate immune modulation in the absorptive period of ectothermic animals. This study aimed to investigate the effects of feeding on endocrine and innate immune responses in the Bullfrog (*Lithobates catesbeianus*). Adult males were divided in two groups: fasted and fed with fish feed (5% of their body masses). Blood and gastrointestinal tract tissues (stomach and intestine) were collected 6, 24, 48, 96 e 168 hours after feeding for measurement of neutrophil/lymphocyte ratio, plasma bacterial killing ability, corticosterone and plasma melatonin; and stomach and intestine melatonin. Feeding increased neutrophil/lymphocyte ratio at 6 h, 24 h and 96 h; and plasma corticosterone at 24 h. Fasting increased plasma corticosterone at 168 h. We also observed decreased bacterial killing ability and increased intestine melatonin 48 h after feeding. Meanwhile, stomach melatonin increased 168 h after fasting. Overall, feeding modulating immune response and the systemic hormonal and intestinal profile, as well as, fasting modulated stomach and plasma hormonal profile. We conclude that, as in mammals, feeding and fasting are able of modulating immunoregulatory hormones and systemic immune response of Bullfrogs.

P25-5 Finkler, MS; Indiana University Kokomo; *mfinkler@iu.edu*
Effects of low temperature early in incubation on embryonic growth and development in Chelydra serpentina: implications of a slow start
Embryos may encounter changes in temperature as incubation progresses. Given that the thermal sensitivity of growth and development tends to decrease over the course of incubation, variation in thermal conditions during early incubation may have lasting effects on these processes even if sustained warmer temperatures occur later. In this experiment, I began incubating snapping turtle eggs in two groups at 20° C then increased temperature weekly by 1.0° C or 2.0° C, respectively, for five weeks until reaching final temperatures of 25.0° C or 30.0° C, respectively. Two additional groups of eggs were incubated at constant temperatures of 23.5° C and 27.0° C, which are equal to

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the respective mean temperatures experienced by the eggs in the two changing temperature groups. Samples of embryos were staged, and wet and dry masses were measured, at 25 days (when temperatures in the changing temperature groups reached the temperatures of their corresponding constant temperature groups) and at 49 days into incubation (after embryos in the changing temperature groups had spent two weeks at their final temperatures). Embryos from the changing temperature groups were both smaller and less developed than their counterparts in the constant temperature groups at both sampling intervals. Hatching occurred later in the changing temperature groups, and both live mass and carapace length were smaller in the higher changing temperature treatment (20 to 30° C) than in the 27.0° C constant temperature control. These findings suggest that slow growth and development due exposure to low temperatures early in incubation cannot be readily compensated for by higher temperatures later in development.

P13-7 Fischer, F*; LaRocca-Stravalle, Z; Gillen, K; Kenyon College; *gillenk@kenyon.edu*

Regeneration in Lumbriculus variegatus entails differential expression of telomerase reverse transcriptase

Functional telomeres are required for genomic stability and continued cell proliferation. Increased expression of telomerase reverse transcriptase (*tert*), the catalytic subunit of the telomerase holoenzyme, helps prevent cellular senescence and maintains proliferative capacity in mitotic cells, while low expression parallels cell differentiation. Despite the importance of telomerase for cellular processes necessary for tissue regeneration, few studies have examined *tert* expression in annelids. *Lumbriculus variegatus* (Annelida, Oligochaeta) regenerates bidirectionally following transverse amputation or asexual fission, and also displays continuous posterior growth that is independent of regeneration. We examined *tert* expression in *L. variegatus* to further investigate the role of telomerase during regeneration. *Tert* was expressed constitutively in intact worms, which may indicate the presence of self-renewing stem and/or germ cells that participate in normal growth. Upregulation of *tert* in segments undergoing extensive cell proliferation associated with epimorphic regeneration implies that *tert* may function to maintain

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proliferative capability in mitotic cells. Interestingly, *tert* was downregulated early during the regenerative process (24 hours post-amputation). As decreased *tert* expression is often associated with cell differentiation and apoptosis, it is tempting to hypothesize that modulation of *tert* expression may play a role in wound healing or regeneration. In the future, we plan to examine telomerase protein activity using the TRAP assay and analyze global transcriptional changes via transcriptomics.

P11-6 Fitch, OE*; Thompson, AW; Braasch, I; Department of Integrative Biology & Program in Ecology, Evolution, and Behavior (EEB), Michigan State University, East Lansing, MI; *fitcholi@msu.edu*

A tale of two tails: Developmental evolution of a key innovation in the fish caudal region

Teleost fishes make up almost half of extant vertebrate biodiversity. The evolutionary success of teleosts has been attributed to the emergence of a homocercal configuration of their caudal skeleton. Considered a synapomorphy and key innovation of teleosts, homocercality, i.e. superficial dorso-ventral (DV) symmetry, enables more sophisticated modes of swimming compared to the ancestral heterocercal condition, i.e. DV asymmetry. The genetic evolutionary mechanisms underlying the emergence of the homocercal configuration in the teleost ancestor have yet to be uncovered. We test the hypothesis that differential outgrowth of two caudal structures in fish, 1.) the 'tail' (the terminal notochord and associated structures) and 2.) the caudal fin ultimately resulted in the diversity of caudal morphologies in ray-finned fishes and vertebrates in general. We compare caudal development in the homocercal teleost zebrafish (*Danio rerio*) with the heterocercal spotted gar (*Lepisosteus oculatus*), representing the closest living outgroup to teleosts, through comparative genomics, morphological studies, gene expression analyses, and chromatin profiling, we identify candidate genes and regulatory elements for caudal region development and evolution among ray-finned fishes.

P25-6 Florendo, JS*; Hatcher, M; Irving, D; Maia, A; University of

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Temperature effect on metabolism and muscle mechanics of Narragansett fishes

The ability of organisms to adapt to changing environments will determine their tolerance to climate change and other anthropogenic pressures. In order to see the effect on coastal fish species, we investigated how raising water temperature affected the metabolisms of four Narragansett Bay fish species: summer and winter flounder, black sea bass and scup. We expect fish species to increase reliance on red muscle under higher temperatures since these muscles are thermal sensitive. Sedentary species will likely demonstrate less capacity to adapt to higher temperatures than more active pelagic species. We used close chamber respirometry to determine mass corrected basal and maximal metabolic rate. We also performed electromyographic recordings to determine in vivo muscle activation patterns of both red and white muscles at half and three quarters of the fish body length. We held the fish at 20C and tested four temperatures: 18, 20, 22 and 24C. We found that while oxygen consumption generally increased with temperature, in flatfishes it increased little or decreased, suggesting depression of metabolism. Basal metabolic rate in scup increased more pronouncedly at higher temperatures than black sea bass, which could indicate increased stress and lower aerobic scope. Muscle mechanics show species specific trends and a trade-off between intensity and duty factor. A higher dependency of red muscles as temperature increased was found for all the species. Studying in vivo muscle physiology and oxygen consumption of various fish species can help determine fitness in the coming years and can be used as input into productivity models. This information is essential to local stakeholders to determine management directions to achieve long-term fishery sustainability.

P26-4 Foltz, SL*; Austin, A; Radford University; *sfoltz3@radford.edu*

Environmental factors related to foraging activity in a semi-terrestrial salt marsh crab

Armases cinereum, the squareback marsh crab, is a small omnivorous semi-terrestrial crustacean commonly found along the eastern coast

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of the United States from Maryland south to Florida. Because of their broad diet and use of a range of habitat types across the ecotone, from tidally flooded *Spartina* beds to upland pine forest, these crabs may be important vectors for nutrient flow within this system. They are also often found in close proximity to humans, raising the question of how coastal development may impact this species and, through it, the functioning of these adjacent ecosystems more generally. As a prelude to studying how human activity and marsh-adjacent structures impact *A. cinereum's* behavior, we conducted pilot work to identify environmental factors correlated with crab foraging activity. Feeding arenas (one sand-coated, one uncoated white plastic) baited with blue crab scraps were set up near the high-tide line and we video-recorded feeding activity at these locations for 20 minute periods within 1 hour of high tide, across a range of times and temperatures. To test crabs' responses to nearby human activity, a researcher was positioned within 2m of the feeding arenas for some observations. Here we present preliminary data on the relationships between time of day, temperature, feeding area substrate, and nearby human presence on crabs' willingness to feed in baited locations. We predict that crabs will be most active at moderate temperatures and at times close to sunrise and sunset rather than at midday when temperature and light levels are highest. We also predict that crabs will prefer to feed on substrates similar in color and texture to bare ground, rather than a high-contrast plastic surface, and that they will forage less in the presence of humans.

P5-9 Frakes, JI*; Birrell, JH; Shah, AA; Woods, HA; Univ. Montana; *jameson.frakes@umontana.edu*

Temperature and oxygen tolerance limits of an aquatic insect depend strongly on water flow

For aquatic insects, extracting sufficient oxygen from water is challenging, as molecules of oxygen move approximately 300,000 times slower and are ~33 times less abundant in water than in air. Interactions among abiotic factors, including temperature, oxygen concentration, and flow, influence supply and demand of oxygen to aquatic organisms. Although recent studies have focused on the joint effects of temperature and oxygen, they have largely ignored

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the effect of flow. Low flows generate thick boundary layers-regions of slow-moving fluid that form around solid objects in a liquid. The boundary layers that form around respiratory exchange surfaces of an aquatic insect, for example, can act as barriers to oxygen diffusion when they are thick, as in slow-moving water. Thus, flow should alter oxygen delivery to insects and should modify sensitivity to other abiotic factors like temperature and oxygen concentration. We tested this hypothesis by subjecting salmonfly nymphs to temperature and oxygen ramps with flow and without flow. We recorded two behavioral stress responses; loss of righting response and ventilatory 'pushups'. We show that water flow velocity strongly influenced respiratory oxygen supply to an aquatic invertebrate (stonefly, *P. californica*), presumably by altering the rate of delivery. As predicted, the addition of flow (10 cm s^{-1}) increased heat tolerance by ~4°C and hypoxia tolerance by an average of 15% of oxygen levels at air saturation. Climate change is predicted to alter abiotic factors in streams worldwide. Our results indicate that warming paired with reduced oxygen concentrations and/or flow in streams may challenge many aquatic ectotherms.

P38-4 Frolova, AD*; Retchless, D; Miglietta, MP; Texas A&M Univeristy at Galveston; *frolova.alexandra@tamu.edu*

Predicting habitat suitability for Scyphozoan jellyfish (Phylum Cnidaria) in the Gulf of Mexico

Jellyfish belonging to the Class Scyphozoa (Phylum Cnidaria) can form aggregations, termed "blooms," which are both ecologically important and sometimes problematic for human enterprise. Scyphozoan jellyfish have a multi-modal life-cycle where the benthic polyp seasonally produces free-swimming medusae. Although medusae are commonly observed, wild polyps have not been found in the Gulf of Mexico and information regarding their habitats is extremely limited in the Gulf as well as globally. To address this knowledge gap, we combined previously published tolerance ranges for temperature and salinity with spatial environmental data for the Gulf of Mexico and performed GIS spatial analyses to identify suitable habitats and settlement surfaces for polyps of two species of Scyphozoa, *Aurelia* sp. 9 and *Aurelia* sp. new, in the Gulf. Habitat suitability was based on the climatological annual minimum

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and maximum values for temperature and salinity calculated at each depth of a grid in the Gulf of Mexico basin. Potential settlement surfaces in the forms of oil and natural gas rigs, artificial reefs, and coral reefs were mapped to the suitable habitats for each species. Coastal waters of the Gulf of Mexico were suitable for *A.* sp. 9, but not *A.* sp. new. Water temperature, but not salinity, was found to be the limiting environmental parameter for both species. Summer high water temperatures in nearshore and coastal areas of the northern Gulf of Mexico restrict *Aurelia* sp. new polyps to the deeper shelf waters, which have fewer potential settlement surfaces.

P11-2 Fukushima, T*; Siddall, R; Byrnes, G; Nyakatura, J; Toussaint, S; Jusufi, A; Max Planck Institute for Intelligent Systems, Siena College, Humboldt Universität zu Berlin; *ardian@is.mpg.de*

Self-righting in squirrels during unexpected falls - towards the crucial function of bushy tails in arboreal mammals

Arboreal mammals navigate a highly three dimensional and discontinuous terrain. Tail use has been observed in many species and despite specializations, fractures from falls have been observed for example in primates. Among arboreal mammals, squirrels are widely observed to be among the most maneuverable. A recent video on YouTube went viral that showed squirrels (*Sciurus carolinensis*) voluntarily visiting the YouTuber's garden cross a parcour to earn a food reward. When 'failing' one of the tasks, the squirrels were catapulted off the track inducing an initially uncontrolled rotation of the body. We preliminary analyzed from the video that firstly the squirrels rotate their tails to stabilize the head to visually fix the landing site. Then, the tail starts to rotate to induce a counter moment to slow down and eventually stop the body rotation preparing the squirrel for the landing. To test the hypothesis that squirrels could utilize tails during mid-air reorientation, and gain insight into tail function essential to the mechanics of this remarkable self-righting behavior, and based on basic spatio-temporal information that we extracted from preliminary observations of *Sciurus carolinensis*, we use an analytical model to predict squirrel kinematics on unexpected ballistic trajectories. Righting maneuvers are optimized in a

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multibody model which computes tail trajectories. This model is also used to explore the limits of inertial aerial righting. To further substantiate this model and demonstrate the underlying mechanics, we developed an abstracted squirrel robot completed with an actuated tail to replicate self-righting behavior. The squirrel-inspired physical model uses two high speed brushless motors to create a 2-DoF tail capable of rapid impulsive movements to test mid-air righting in a physical model.

P40-11 Furgal, RC*; Lessios, NN; Assumption University; *raymond.furgal@assumption.edu*

The unusual ventral light reflexes of fairy shrimp

Crustaceans are a sub-phylum of arthropods that have all the eye "designs' found in animals. Dorsal light reflexes are widespread in many aquatic animals, including crustaceans, and are behavioral responses to light in which the animal presents its dorsal surface towards a light source. Branchiopods are a group of crustaceans that are often found in temporary pond habitats, and are thought to predominantly use light cues for orientation. Fairy shrimp (Branchiopoda: Anostraca) are unusual because they generally swim with their ventral side upward, which correlates with the direction of light that is typical for temporary pond environments. Fairy shrimp could use a ventral light reflex for orientation purposes. In other arthropods, such as flying insects, simple eyes called ocelli are used for stabilization and orientation during flight. It remains to be seen whether anostracans generally use their simple eyes, or compound eyes, for light orientation in their habitats. Here, we summarize findings of the dorsal light reflex of a subset of crustaceans. We also ask: how widespread are ventral light reflexes? Could excitatory/inhibitory pathways for reflexive behavior be reversed in fairy shrimp?

P38-9 Furman, DR*; Halvorsen, SK; Clark, K; Adolph, SC; University of Pennsylvania, Harvey Mudd College; *adolph@hmc.edu*

Modeling the climatic niche and geographical distribution of the desert night lizard, Xantusia vigilis

The desert night lizard (*Xantusia vigilis*) is a habitat specialist abundantly spread across arid regions of the North American

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southwest, often reliant on fallen Joshua tree branches (*Yucca brevifolia*) for shelter. Future climate change impacts on *Y. brevifolia* are therefore of particular concern for the lizard's ecological conservation. Here, we explored the impacts of climate change on *X. vigilis*' geographical distribution using a Species Distribution Model (SDM) of its climatic niche, additionally aiming to relate these responses to those for *Y. brevifolia*. We trained the SDM with a set of ten uncorrelated WorldClim Bioclimatic variables (1970-2000 averages) and presences of each species (>1000 unique locations). A random forest classifier performed best from a set of over ten candidates (including Maxent), emerging as the best predictive model of the current geographic distribution (e.g., OOB misclassification error ~ 2-3%). We then projected the SDM to future climate conditions, simulated with eight climate models from CMIP6 over four Shared Socioeconomic Pathways, for the years 2040-2100. Under these scenarios the range of *X. vigilis* was predicted to decline to between 11% to 55% of its current range, assuming little or no dispersal. In addition, a single climate model, CanESM5, consistently predicted the most dire scenario of future habitat suitability. We also measured overlap with projections of *Y. brevifolia*'s distribution. Our results highlight the importance of including symbiotic and other ecologically important species into models of climate change effects on geographic distributions, with conservation risks possibly heightened for localities which face extreme climate events, such as wildfires.

P18-4 Gabor, CR*; Aspbury, AS; Chester, SM; Texas State University, San Marcos, TX; *smc209@txstate.edu*

Land use conversion affects life-history traits of western mosquitofish

As land use conversion increases through urban development, there are noticeable increases in the impervious cover that heavily contribute to urban stream syndrome. These modifications are associated with shifts in water quality, altered hydrology, and reduction of biotic richness. Some tolerant fish species modulate their life-history traits, such that they increase or retain their reproductive rate and persist in urbanized environments. The Western mosquitofish, *Gambusa affinis*, is a native species of live-bearing fish that is tolerant to change. We hypothesized that

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increasing urbanization, defined by percent developed land in the water-shed around each site, will affect life-history traits of female mosquitofish. We sampled fish from 6 streams with varying levels of urbanization. We found that total embryo size was largest in the most urbanized (51%) followed by the least urbanized populations (2, 5%). The intermediately urbanized populations (32, 25, 21%) had the smallest total brood size. The most urbanized (51%) population showed a trade-off in brood number and brood size with the lightest individual embryo mass. But the second least developed (5%) and the intermediate populations did not show trade-offs as their individual embryo masses were not as small. Our findings suggest that mosquitofish tolerate urbanization by altering their life-history tradeoffs.

P20-1 Gadey, L*; Dowle, EJ; Powell, TH; Nguyen, A; Papadopoulos, NT; Hahn, DA; Ragland, GJ; University of Colorado Denver, University of Otago, Binghamton University , University of Florida, University of Thessaly; *lahari.gadey@ucdenver.edu*

A remarkably consistent life history trait with a remarkably inconsistent developmental basis: lack of evolutionary conservation of transcriptomic trajectories during tephritid fly diapause

Major landmarks of developmental processes are often highly conserved across phylogeny, e.g., stages of embryogenesis within phyla. This is largely true for arthropods, with a notable exception; many species interrupt the ‘typical’ developmental process when they enter dormancy or diapause. This trait is highly evolutionarily labile, evolving repeatedly and occurring at different developmental stages in different taxa. Previous studies show that clear instances of repeated evolution result in highly divergent diapause phenotypes. However, there are groups of closely related taxa within which the diapause phenotype appears to be phenotypically conserved, consistent with single evolutionary origins. Such is the case for pupal diapause in the *Rhagoletis* genus (Diptera: Tehpritidae); nearly all described members have a single generation per year and overwinter as diapausing pupae just prior to molt into the pharate adult. Here we present results that genetically differentiated populations within *Rhagoletis pomonella* show highly conserved transcriptomic

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trajectories during diapause. However, *Rhagoletis cerasi*, a more distantly related species (~5 mya) with a nearly identical diapause life history demonstrates highly distinct transcriptomic trajectories compared to *R. pomonella*. We describe the quantitative evidence supporting this lack of conservation and discuss implications for the evolutionary flexibility of life histories.

P35-8 Galante, H*; Kittilson, JD; Elderbrock, EK; Heidinger, BJ; Greives, TJ; North Dakota State University; *holland.galante@ndsu.edu*

Are melanistic plumage characteristics a signal of mitochondria number, oxidative stress and fitness in male house sparrows?

Plumage ornaments such as the house sparrow *(Passer domesticus)* badge are often associated with traits correlated with fitness. For example, in several avian species, males with higher saturated red colored plumage and/or darker melanistic characteristics have better body condition, higher levels of antioxidant capacity, and greater over winter survival and lifetime reproductive success. The mechanisms that link these plumage characteristics with traits associated with fitness are not fully clear. Recently mitochondrial copy number (mtDNAcn) has been found to be positively correlated with oxidative damage and antioxidant capacity, related to disease prevalence in humans, and egg and sperm quality in captive mammals. In male house sparrows, badge size is positively related to proportion of offspring fledged, and in other bird species brood size and oxidative stress were positively correlated. Together, this suggests a potential link between badge size and mitochondrial-related metabolic processes and by-products that may influence fitness. Here we test the hypothesis that the melanistic-based badge trait in house sparrows is associated with mtDNAcn and total plasma antioxidant capacity, as well as, the relationship between these traits and reproductive fitness. To investigate this hypothesis, blood samples from male house sparrows were collected during chick rearing to assess mtDNAcn and total plasma antioxidant capacity. Badges were photographed to quantify badge size and color saturation. We predict males with larger and darker badges will have higher levels of total antioxidant capacity, mtDNAcn and fledging success. This

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data will provide a potential underlying mechanistic linkage between ornamentation and reproductive fitness.

P17-11 Game, M*; Smith, FW; University of North Florida; *n01403244@unf.edu*

Conserved and divergent aspects of leg development in Tardigrada

Legs are a defining characteristic of Panarthropoda (Arthropoda, Onychophora, Tardigrada). Arthropod leg development has been extensively studied. To a lesser extent, leg development in Onychophora is also well characterized. However, very little is known about tardigrade leg development. Our studies have revealed several intriguing examples of conservation and diversification of appendage development mechanisms in the tardigrade *Hypsibius exemplaris*. In arthropods, *wnt1* activates *Sp6-9* to specify ventral appendages. This mechanism is most likely conserved in onychophorans. By contrast, *H. exemplaris* is missing *wnt1*. *Wnt4* is expressed in a segmental pattern near where legs will develop in this species. However, as in other panarthropods, *Sp6-9* is strongly expressed in developing legs. In arthropods and onychophorans, the leg gap genes regulate appendage growth and specify proximodistal leg identities. *Homothorax* and *extradenticle* specify the proximal domain, *dachshund* the intermediate domain, and *Distal-less* the distal domain. By contrast, in *H. exemplaris*, *homothorax* and *extradenticle* are co-expressed broadly across most leg buds in *H. exemplaris*, but they are not expressed in the posteriormost leg buds. *Dachshund* has been lost in tardigrade genomes. *Distal-less* is expressed broadly across the leg bud of *H. exemplaris*. A distal patterning network is active downstream of *Distal-less* in arthropods. Many features of this network are conserved in onychophorans. However, of the distal patterning genes thus far investigated, only *aristaless* is expressed in all leg buds during tardigrade development. Placed in a phylogenetic context, our results reveal that leg development has been secondarily simplified in Tardigrada in association with miniaturization.

P27-3 Garcia Neto, PG*; Titon, SCM; Assis, VR; Muxel, SM; Titon Jr, B; Ferreira, LF; Gomes, FR; Fernandes, PAC; University of Sao

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Paulo, Santo Andre Foundation University Center; *pgarcianeto@usp.br*

Effects of immune challenge on immunological and endocrine parameters of Cururu toads (Rhinella icterica) in their natural habitat

Glucocorticoids and melatonin show immunomodulatory functions, acting as stimulators and suppressors of the immune response, depending on the context. In amphibians, there are still few studies on this immune-endocrine interaction in an inflammatory context, all of them under captivity conditions. Evaluating how these animals react in the field to an immune challenge would reveal relevant information regarding how immune-physiological parameters are modulated in natural conditions. This study aimed to evaluate the effect of lipopolysaccharide (LPS) injection at early (9-10 pm) and late night (12-1 am) of toads (*Rhinella icterica*) recently captured in their natural habitat in Atlantic Forest. The following parameters were evaluated: plasma bacterial killing ability, plasma corticosterone, melatonin, and testosterone levels, and gene expression of cytokines and complement system protein (interleukin[IL]-1β, IL6, IL10, interferon-γ, C1S) in the spleen, two hours post-injections. LPS-injection induced an increase in corticosterone plasma levels and the gene expression of IL1β, while no changes were found in the other variables. During the early night, LPS-injected toads had upregulation of IL1β compared with the saline-injected ones, evidencing that LPS induced an inflammatory response. Our results are associated with the first stage of the inflammatory response, and studies evaluating further steps of the immune response might lead to a better understanding of the immune-endocrine relations in amphibians.

P21-4 George, N*; Gaddam, MG; Santhanakrishnan, A; Oklahoma State University; *askrish@okstate.edu*

Feeding currents of upside-down jellyfish: role of oral arm structure

Cassiopea medusae, commonly called upside-down jellyfish, are found in shallow marine environments. Their morphology includes a bell with eight oral arms that consist of multiple secondary mouths. These animals are mostly sessile and are found with their bells resting upside-down on the substrate, with their oral arms directed towards the sunlight. Capture of particulate nutrients and

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incorporation of zooxanthellae are needed for the growth and reproduction of *Cassiopea*. Previous studies have shown that *Cassiopea* bell pulsations serve to entrain water from the surroundings and transport it through the oral arms. An upward jet was observed above the medusa throughout the bell pulsing cycle. What remains unclear is whether three-dimensionality of the bell motion or the elaborate oral arm network helps in maintaining the upward jet. We examine whether oral arms are needed for maintaining a continuous upward jet, in order to identify how this structure impacts feeding currents. 3D particle tracking velocimetry (PTV) measurements (shake-the-box method) were conducted on multiple *Cassiopea* individuals in a laboratory aquarium. 3D PTV measurements showed the formation of a vortex ring at the end of bell contraction and persistent unidirectional flow above the bell, even in experiments where oral arms were excised. To examine how the oral arm structure impacts prey capture, additional experimental studies were conducted using brine shrimp larvae as particles introduced in the water. Flow generated near the oral arms and implications on prey capture will be discussed.

P16-6 Gibson, EF*; Torres-Velarde, JM; Crocker, DE; Vazquez-Medina, JP; University of California, Berkeley, Sonoma State University; *emily.gibson@berkeley.edu*

Prolonged fasting increases DNA methylation in northern elephant seal pups

Northern elephant seals (NES) are naturally exposed to extreme conditions, including prolonged food and water deprivation (fasting). NES pups are born during the spring, initially nursing for a month before they are weaned and fast for two months. During this fasting period NES pups lose about 25% of their body mass, while maintaining biochemical homeostasis and supporting muscle development. At the end of their post-weaning fasting, NES pups depart the rookeries to forage before returning in the fall for their semiannual resting haul out. The environment, especially stressful environmental conditions, can modify the methylation status of DNA, consequently regulating gene expression. We compared global DNA methylation percentages between early-fasting (1-2 weeks), late-fasting (7-8 weeks), and 0.8-year old NES pups. DNA was extracted from white blood cells collected from NES pups

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sampled at Año Nuevo State Park, CA, and global DNA methylation was measured using an Abcam™ Global DNA Methylation Assay Kit. Prolonged fasting significantly increased global DNA methylation (p=0.0061) in NES pups, while 0.8 year old pups showed a return to global methylation levels comparable to the early-fasting animals, suggesting a transient decrease in transcription activity during the fasting period. We are in the process of identifying changes in specific genes involved in growth, hypoxia tolerance, and metabolism by analyzing the methylation status of CpG islands in putative promoter region sequences. Our initial results suggest that DNA methylation is an important regulator of transcription and gene expression during natural, prolonged food deprivation.

P17-6 Gibson, MG*; Crawford, K; St. Mary's College of Maryland, St. Mary's City, MD; *kcrawford@smcm.edu*

Filling in the gaps: Fibroblast growth factor 10 induced intercalary regeneration in salamanders

The axolotl, *Ambystoma mexicanum*, is an important model organism for the study of regeneration. After limb amputation a wound epidermis covers the surface of the stump and a regenerating bud of tissue or blastema forms, proliferates, and differentiates to restore all the limb elements that were lost. Although a blastema is only able to regenerate structures distal to its plane of amputation, when a wrist level blastema is grafted to a more proximal limb stump, it induces intercalary regeneration and a complete limb is restored. In contrast, creating the same proximodistal discontinuity, by grafting a freshly amputated hand or foot (autopod) to a more proximal limb stump, results in a truncated limb and does not induce intercalary regeneration. As a result, the mature autopod appears to lack the proper signals necessary to instruct the stump to fill in the gap, to dedifferentiate and intercalate the missing limb elements. These experiments create an opportunity to decipher the molecular signals responsible for intercalary regeneration and possibly regeneration itself. Through juxtaposition of beads charged with growth factors between a mature hand graft and more proximal limb stump it may be possible to determine the signals that initiate and drive intercalary regeneration in salamanders. Here we present a compilation of several studies in which we observed intercalary

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regeneration driven by fibroblast growth factor 10 as compared to control groups. However, graft displacement, amputation level and bead expulsion were all factors that appear to affect the regenerative patterns we observed. These results and future studies designed to optimize these elements will be discussed.

P34-9 Gilbert, FR*; Brandley, NC; College of Wooster; *egilbert252@gmail.com*

Implications of background variation on color variation within a population of Carolina grasshoppers

Classical natural selection theory suggests that a camouflaging species should resemble their environment. However, what if a species inhabits an area that frequently varies in background color? The Carolina grasshopper (*Dissosteira carolina*) is a generalist species that inhabits many different backgrounds. Notably, within the same population *D. carolina* individuals may vary in color including on a brown to grey spectrum. How do these alternative colorations perform on the variety of backgrounds present within their habitat? To explore this question, we measured reflectance of grasshoppers collected in northeast Ohio. Using bird visual modeling, we examined how well the grey (n=23) and brown (n=27) colorations matched various natural backgrounds. Each coloration appeared advantageous against some backgrounds. The brown grasshoppers matched dirt better than grey grasshoppers (color distance for brown= 0.03 and grey= 0.045; p=0.006; smaller values indicate better match) and grey better matched grass (brown=0.13 and grey= 0.12; p=0.0001) and grey rocks (brown=0.095 and grey=0.065; p=0.003). This suggests each coloration within *D. carolina* populations could have some camouflage advantage on different backgrounds. This supports the notion that background matching can lead to the persistence of alternative colorations in variable environments. However, research on which background each variant spends more time would provide some much-needed insight on whether this is advantageous.

P18-2 Gomez, A*; Wang, X; Rodriguez-Santiago, M; Boughman, JW; Hofmann, HA; Ålund, M; Young, RL; UT Austin, Michigan State

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Sensory transcriptomes across variable environments

As natural and human-induced climate change forces organisms to adapt to changing environments and colonize new habitats, survival is dependent on their ability to respond to novel ecological challenges. Here, we use the three-spined stickleback fish *Gasterosteus aculeatus* to ask how adaptation to novel environments is reflected in the neuromolecular processing of three sensory modalities - olfaction, vision, and mechanosensation. Originally found in marine habitats, sticklebacks exhibit an impressive capacity to adapt to widely different environments, having invaded freshwater lakes and streams across the Northern hemisphere. We collected 64 fish in 8 distinct populations from marine, lowland spring-fed, highland spring-fed, and highland glacial waters in Iceland. The habitats vary in nutrient availability and water clarity among other ecological factors. Specifically, lowland and highland spring waters are clear and low in nutrients; marine environments are clear to turbid and high in nutrients; glacial waters are very turbid and nutrient-rich. Using a common garden experiment, we find that fish from different habitats show distinct behavioral responses to predator simulation experiments. Next, we assess variation in the transcriptomes of three sensory brain regions - olfactory bulb (OB, olfaction), optic tectum (OT, vision), and torus semicircularis (TS, mechanosensation) - across habitats and in response to a predator. We identify gene expression differences across populations and environments and gene co-expression modules associated with predator avoidance behavior. Our results reveal how variation in selective pressures and evolutionary divergence are reflected in transcriptomic changes in the brain.

P5-1 Gravelle, JM*; Wyneken, J; Florida Atlantic University; *jgravelle2018@fau.edu*

The effects of multiple environmental factors on the hatching and emergence success of loggerhead sea turtles (Caretta caretta)

Many environmental variables affect the success of incubating sea turtle eggs. Multiple studies examined how different environmental factors (e.g., temperature, moisture, sand characteristics, and predators) affect the hatching and emergence success of loggerhead

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sea turtle (*Caretta caretta*) nests. However, the specific combination of factors that produce the highest numbers of hatchlings is not well understood. Here we explore the combinations of environmental factors that correlate with highly successful nests. We analyzed 25 years of loggerhead hatching and emergence success data from Florida's Atlantic coast to identify which portions of nesting beaches produce the most successful nests. During the summer of 2020, we also collected new hatching and emergence data and associated environmental variables (e.g., internal nest temperature, sediment characteristics, nest location) from 50 nests within the high-success portions of each nesting beach. We test hypotheses about which environmental variables best explain hatching and emergence success and discuss the implications of our findings within the context of early hatchling survival. All historically successful nesting sites varied in average daily nest temperature, sediment sorting, sediment salinity, and carbonate content, suggesting that an interaction of these factors is tolerated by incubating eggs, allowing for a high hatchling yield.

P39-1 Gregory, CL*; Bradford, EL; Belden, LK; Virginia Tech; *caseygregory@vt.edu*

Changes in the composition of honey bee (Apis mellifera) gut bacterial communities following disturbance by antibiotics

Disturbance of microbial communities can have notable effects on biological systems due to the important ecological roles of microbes. For instance, symbiotic host-associated microbial communities impact host physiology and can be disturbed by many factors, including antibiotic exposure. Advancements in sequencing technologies have allowed ecological questions to be addressed more thoroughly in microbial systems. Previous research has shown that different microbial communities may respond differently to disturbance. This study addressed the impact of antibiotic perturbation on the bacterial communities in the honey bee gut microbiome. Honey bees are a good candidate for microbiome studies because they harbor gut communities with relatively low taxonomic diversity. We treated honey bees with low doses of tetracycline to identify how gut communities change following antibiotic exposure. Prior studies have demonstrated impacts of antibiotics in this system, but we used fecal sampling to account for variation in

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individual bees before and after exposure. Fecal samples were collected from individually-marked caged bees before, and five days after antibiotic treatment. We assessed changes in gut bacteria community structure using 16S rRNA gene amplicon sequencing. Our preliminary analysis suggests differences in the gut bacterial taxa present in the bees after disturbance with antibiotics.

P7-9 Griner, JG*; Palecek, AM; Diamond, KM; Schoenfuss, HL; Blob, RW; Clemson University, Seattle Children's Research Institute, St. Cloud State University; *jggrine@g.clemson.edu*

Geometric morphometrics of climbing kinematics in waterfall climbing goby fishes

The terrestrial locomotor abilities of amphibious fishes have received attention as a model for the water to land transition in vertebrates. Another striking locomotor mechanism found among some amphibious fishes is the ability to climb vertical substrates. In gobioid fishes, climbing is accomplished through two distinct mechanisms: inching and powerburst climbing. Powerburst climbers attach using a pelvic sucker and generate thrust using fins and lateral body bending to climb with short bursts of movement. In contrast, inching climbers use longer, sustained periods of movement, alternating attachment between oral and pelvic suction disks. Although the use of these disks has been recognized in previous studies, how these suction disks attach and detach during the climbing cycle requires further investigation. We predict that the kinematics of the suction disks will be repeatable within the different climbing modes and differ between powerburst and inching climbers. To test this, we tracked the motion of the suction disk throughout the climbing cycle using high-speed video and used geometric morphometrics to quantify the change in shape of the pelvic sucker over time. We found that within each cycle, the powerburst climbers had a highly repeatable pattern of sucker movement: a stationary period for roughly 70% of the cycle followed by a rapid change in shape with the movement of the fish. Inching climbers also experience a change in shape upon body movement, but the point of initial sucker movement is more variable within the cycle. These results suggest that having a second sucker, which allows for continuous contact with the substrate, may allow inching climbers to exhibit a greater kinematic range in their attachment.

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P25-10 Gudde, E*; Levesque, D; University of Maine; *elise.gudde@maine.edu*

The response of Northern flying squirrels to rising ambient temperatures

Climate change has the potential to alter entire ecological systems, including species' range distributions. Both species of flying squirrel (Glaucomys volans and G. sabrinus) in North America have undergone dramatic range shifts northward over the past few decades, with rising temperatures being the suspected driver. The relationship between animals and their thermal environment has been gaining attention in the fields of ecology and physiology, and while other studies have focused on warming winter climates, we examine the rising summer temperatures as a driver of observed range shifts. We focused on the northern flying squirrel (Glaucomys sabrinus) to determine the effect of high temperatures on thermoregulation and energy use. We measured resting metabolic rate and subcutaneous body temperature of northern flying squirrels across a range of ambient temperatures using flow-through respirometry. We also measured free-ranging core body temperature of the species. The use of models that combine biophysical principles and climate data will also help to test predictions a way to test predictions of geographical patterns derived from biophysical mechanisms. This research will help us to understand the relationships between activity patterns and vulnerability to climate change, and will help to further our understanding of global patterns in mammalian thermoregulatory characteristics.

P10-5 Guruvadoo, AR*; Miller, CW; Forthman, M; University of Florida, California Department of Food and Agriculture; *aguruvadoo@ufl.edu*

Reproductive trade-offs in the Soapberry Bug Jadera haematoloma (Herrich-Schäffer, 1847) (Insecta: Hemiptera: Rhopalidae)

According to sperm competition theory, sexually selected weapons compete for resources with other reproductive traits, such as the testes. Because these traits trade-off, males cannot optimally invest in both traits, and thus may maximize weapons or testes, but not both. Leaf-footed bugs (Hemiptera: Coreoidea) have been

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extensively researched to understand the trade-offs between their hind legs weapons and testes. However, previously published studies on reproductive trade-offs in the Coreoidea have only investigated species with these exaggerated hind legs that function as weapons, but not all species of Coreoidea use their hind legs as weapons. Thus, it is unclear if the documented trade-off is due to the roles of these traits in reproduction, because they contain costly tissues, or for another reason. We selected a Coreoidea species that does not use its hind legs as weapons, *Jadera haematoloma* (Rhopalidae). We determined whether males of this species reallocates resources to their testes when a hind leg is lost. We induced leg loss in young *J. haematoloma* and we later weighed each reproductive adult's testes mass. These results will contribute to our fundamental understanding of resource allocation, sexual selection, and evolution of mating systems.

P38-1 Gusmao, LC*; Rodríguez, E; American Museum of Natural History, New York, NY; *Gusmaolc@gmail.com*

Bipolar distributions in sea anemones (Cnidaria: Anthozoa: Actiniaria): the case of Halcampoides Danielssen, 1890

Bipolarity is a well-known phenomenon of single, closely related, or even unrelated marine families, genera, or species found exclusively on high latitudes or on high latitudes and the deep-sea of the tropics. The bipolar distribution patterns may have developed differently among groups and may include one of many explanations (e.g. Relict Theory and its modifications, Contemporate migrations, deep-water migrations, etc). The order Actiniaria has eight families and 12 genera with bipolar distributions. Among these bipolar genera, *Halcampoides* includes large, burrowing anemones that are easily distinguished by their unique morphology (i.e. six pairs of mesenteries and 12 tentacles). The genus initially included one species with bipolar populations spread across the North Atlantic, Mediterranean, the Arctic, and Antarctica. After taxonomic changes and species reassignments, *Halcampoides* is currently comprised of two valid species: type species *H. abyssorum* in the northern hemisphere and *H. purpureus* from Antarctica. *Halcampoides* spp. have very uniform morphologically, as is the case for most genera with bipolar species which are primarily differentiated by geography. We

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combine morphology (anatomy, microanatomy, micro-CT scanning), molecular data (nuclear and mitochondrial markers, and mitochondrial genomes), and cnidae to provide reliable species identification and discern broader biogeographic patterns and evolutionary processes. We also discuss the implications of our findings for the taxonomy of the family Halcampoididae, the evolution of burrowing anemones, and the bipolar phenomenon in Order Actiniaria.

P34-3 Gustafson, TM*; Fitak, RR; University of Central Florida; *tarygustafson@knights.ucf.edu*

Characterizing the sialin gene family expansion in Cephalopoda: Neurogenomic insights into invertebrate intelligence

Octopuses and other cephalopods are uniquely valuable for comparative neuroscience. Octopuses, with the largest relative brains of any invertebrate, display sophisticated behaviors often ascribed only to complex vertebrates. While the capabilities of the octopus nervous system are similar to those of vertebrates, cephalopod brains evolved independently of the vertebrate brain. This combination of neural complexity and evolutionary distance from humans make cephalopods ideal for understanding how complex cognition can evolve. Despite the importance of this question, the genomic mechanisms underlying cephalopod cognition are not well understood. It has been hypothesized that nervous system complexity in the octopus may have evolved via several gene family expansions, including the sialin gene family. While sialins are involved in neurotransmission and are expanded in the octopus genome, their role in cephalopod evolution has not yet been explored. Here, we characterize the evolutionary history of the sialin family to better understand the octopus nervous system. We first identified the number of sialins in 39 bilaterian genomes, including 5 cephalopods. Next, we predicted the sialin count for each ancestor of these species using a gene birth-death model. Our reconstruction predicted a rapid expansion from 23 sialin copies in the ancestral cephalopod to 39 in octopods, suggesting that the sialin expansion occurred specifically in the octopus lineage. Future aims of this study include determining the rate of sialin evolution across cephalopods and predicting the function of sialins in the octopus

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nervous system. Our research will provide insights into the evolutionary roles of sialin in cephalopod neurobiology.

P7-4 Hagood, ME*; Porter, ME; Florida Atlantic University; *mhagood2018@fau.edu*

Anisotropic structural and mechanical properties of shark skin

Shark skin may act as an exotendon altering swimming performance among species with varying ecologies. Shark skin is a material composed of dermal denticles embedded in the stratum compactum of the dermis, where an elastic network is formed between denticles and collagen fibers. This network stretches in two distinct orientations of uniaxial stress (longitudinal and hoop), transmitting muscular and controlling tensile forces during swimming. Previous work on shark skin showed that denticles and collagen fiber networks impact mechanical properties. Our goal is to quantify the anisotropic properties of shark skin and the impacts of the collagen fiber network and dermal denticle density among four shark species. We dissected skin between the two dorsal fins and created a grid around the body. We imaged each grid cell (5x5cm) using a stereoscopic microscope and quantified denticle density on the external and collagen fiber angle on the internal skin surface using ImageJ. Four dog-bone shaped samples, 2 at each orientation (longitudinal and hoop), were tested in tension until failure at a 2 mm/s strain rate on an Instron E1000. We generated a stress-strain curve for each sample and calculated the tensile properties: ultimate strength (MPa), maximum strain (mm-2), toughness (MPa), and Young's Modulus (MPa). We found significant differences among species for all mechanical properties, and testing orientation was significant for all mechanical properties except toughness. As collagen fiber angle and denticle density increase, toughness decreases. These data improve our understanding of the role of shark skin in swimming mechanics for energy reduction and meeting demands in various habitats, thereby potentially acting as an exotendon.

P32-4 Hahn, TP*; Dingle, H; Ramenofsky, M; Cussen, VA; Watts, HE; Cornelius, JM; Univ of California Davis, Washington State Univ, Oregon State Univ; *tphahn@ucdavis.edu*

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Fuel reserves or fueling en route? Scouting Trip versus Wandering Search strategies for nomadic migrants

Migration is an energetically expensive strategy to avoid adverse conditions and locate resource peaks. Many migrants follow predictable routes of known distance, allowing reliance on large energy reserves to fuel migration, with occasional refueling at consistent stop-over sites. Predictability of route, distance, and resources favor this strategy. Nomadic migrants that search for unpredictable resources cannot know the distance or route they must traverse. How do such migrants fuel these nomadic movements? Here we propose two strategies for solving this problem: Scouting Trip and Wandering Search strategies. For Scouting Trips, the animal deposits fat and then goes on an exploratory Scouting Trip, the maximum length of which is limited by the fat stores. If no rich patch suitable for settlement is discovered, the animal turns back while it still has sufficient reserves to get to the original starting point, where it refuels for another Scouting Trip. A variant of this strategy is to stop at a new refueling point discovered somewhere along the way on the Scouting Trip, and to use that as a new point of origin for the next Scouting Trip. The Wandering Search strategy, in contrast, is an open-ended exploratory trip fueled primarily by feeding en route. Fat reserves can be much smaller than for Scouting Trips, and stops to refuel would be frequent. This strategy requires that sufficient food for refueling be present essentially all along the travel route. We discuss factors that favor each of these strategies, and present evidence that one nomadic migrant, the red crossbill, employs primarily Wandering Search.

P22-3 Hamant, EL*; Frakes, JI; Woods, HA; Univ. Montana; *emily.hamant@umontana.edu*

Leaf choice by salmonfly nymphs (Pteronarcys californica) in western Montana

The giant salmonfly (*Pteronarcys californica*) is the dominant stonefly shredder in many streams and rivers of North America. These stoneflies increase nutrient availability for other herbivores by consuming and processing decomposing leaves. However, riparian tree communities are diverse and produce many species of leaves that have very different chemical characteristics.

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Whether *P. californica* can choose among leaf species as they fall into the stream remains unknown. The consequences of such choices could determine the fitness of *P. californica*. During decomposition, leaves are 'conditioned', i.e., are colonized by microbial and fungal communities. These colonies, along with leaf chemistry and toughness, create variation in the rate of leaf conditioning and alter the rate of leaf decomposition. Shredders gain nutrients by consuming conditioned leaves. Because of variability in conditioning and nutrient quality, we predicted that *P. californica* will prefer leaves that decompose faster under short conditioning periods, but will prefer tough leaves under longer conditioning periods. We first measured stonefly preference among five leaf types based on either leaf species or conditioning time. We then assessed the fitness consequences of those choices by measuring stonefly growth when individuals were fed single leaf types. We found that *P. californica* shifts its preference from faster to slower-decomposing leaves as conditioning time lengthens, but neither leaf toughness nor an advantage in fitness dictates this shift. We show that interactions between riparian tree species and insect growth are complex. Thus, our results indicate that stream restoration efforts should include planting multiple tree species to improve growth and survival of invertebrates and the quality of the stream community.

P29-7 Hamar, JC*; Kültz, D; University of California, Davis; *jchamar@ucdavis.edu*

Efficient CRISPR/Cas9 gene editing in a tilapia cell line model using endogenous promoters

Cell cultures are effective supplemental models to study specific biochemical pathways used for environmental adaption in animals. They enable isolation from system influence and facilitate control the extracellular environment. For work focusing on fish species many representative cell lines now exist, including a tilapia brain cell line (OmB) developed in our lab. CRISPR/Cas9 gene editing is an additional tool aiding these studies by allowing manipulation of specific genetic loci and evaluating their causal relationship between phenotypes of interest. However, established CRISPR/Cas9 gene targeting tools and methods often have not functioned as efficiently in fish cells as seen in other animal cell models such

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as mammalian cell lines, consistent with our initial attempts to apply CRISPR/Cas9 in OmB cells that failed to indicate genomic alteration at the targeted sites. Poor expression of heterologous promoters in OmB cells was hypothesized to be a primary cause for this occurrence so we constructed a custom plasmid vector based system utilizing tilapia endogenous promoters (EF1 alpha to express Cas9 and a U6 to express gRNAs). This system demonstrated substantial editing of most target sites attempted with mutational efficiency as high 80%. This work specifically highlighted the importance of phylogenetic proximity in selection of a polymerase III promoter for gRNA expression as commonly used interspecies U6 promoters (human and zebrafish) yielded no detectable gene editing when applied in this system with a common gRNA target sequence. These new tools will allow generation of knockout cell lines for gene targeting studies in tilapia and other phylogenetically close fish species. This study was funded by a grant from NSF (IOS-1656371) and BARD (IS-4800-15 R).

P9-2 Haney, RA*; Abedini, Z; Haney, EB; Garb, JE; Ball State University, St. Lawrence University, University of Massachusetts Lowell; *rahaney@bsu.edu*

Genomic and transcriptomic data define a diverse assemblage of small cysteine-rich proteins in the common house spider genome

In venomous invertebrates, such as spiders, small proteins rich in cysteine residues and disulfide bonds are known for their function as toxins, often adopt a compact structural fold referred to as the inhibitory cystine knot (ICK), and target a diversity of ion channels and receptors in prey nervous systems. However, small cysteine-rich proteins with disulfide bonds may adopt a range of potential structures beyond the ICK and serve a multiplicity of functions beyond roles as toxins, though these structures and functions remain obscure in spiders. In the common house spider genome, we identified 709 small, cysteine-rich proteins. These proteins exhibited a wide range of predicted disulfide connectivity patterns, indicating the likelihood that they may adopt distinct structural forms. A total of 147 distinct protein domains were identified in these small, cysteine-rich proteins, the most common of which was thyroglobulin, although the majority of domains (94) occurred in only a single protein. Patterns of expression across

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tissues of small, cysteine-rich house spider proteins were variable, but 143 had strongly biased expression in either the venom gland, the silk gland, or the ovary, with the majority (99) having strongly biased expression in the silk gland. Furthermore, of the 165 small, cysteine-rich proteins that had significant homology to a known toxin, only 10 had strongly biased expression in the venom gland, whereas 61 had strongly biased expression in the silk gland, a pattern which suggests the potential for alternative functions beyond roles as toxins, and as yet undiscovered functions in silk.

P22-7 Hanna, R*; Sustaita, D; Hedrick, T; Rico-Guevara, A; University of Washington, California State University, San Marcos, University of North Carolina; *robhanna@uw.edu*

Flight speeds of hummingbirds during foraging and territory defense

Hummingbirds are capable of unparalleled flight speeds and maneuverability. These feats are utilized during courtship and territorial displays as well as combat. We studied the flight trajectories of various hummingbird species in Colombia in order to characterize the aggressive interactions both within and among species around artificial feeders. We filmed flight trajectories of individuals both attacking and freely departing from the feeders using multi-GoPro arrays. We then processed these videos using ARGUS to obtain 3D trajectories and used MatLab to obtain velocities and accelerations. Our objectives were: (1) To compare flight speeds between freely departing, attacking, and chased hummingbirds, to determine whether these trajectories vary based on the level of aggression. (2) To compare the differences in flight speeds between attacking and chased hummingbirds; are differences consistent across species? We ground-truthed our measurements by calculating the acceleration of gravity from parabolic trajectories of a standard object (tennis ball toss). Our preliminary data indicate a level of accuracy within 6.3%, on average. Thus far we found that the peak 3D velocities and accelerations vary based on the species; *Amazilia franciae* "attackers" achieved higher peak velocities and accelerations than those chased, while *Amaziliae cyanifrons* showed no real differences. The competitive interactions among and within these hummingbirds species around a feeding source

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allow us to quantify the biomechanical performance of their flight in a semi-natural context.

P40-9 Harb, S*; Sawicki, G; Amplo, HE; Flammang, BE; NJIT, Cornell University, Rutgers-Newark, NJIT/Rutgers; *hea7@njit.edu*

Comparing the pectoral girdle and fin morphology in frogfishes

Frogfishes (Family Antennariidae) are a group of primarily benthic predators capable of multiple modes of locomotion. Antennariidae is composed of two subfamilies, Antennariinae and Histiophryninae, and 52 species found in tropical and subtropical ocean waters. Antennariinae and Histiophryninae differ primarily in their distribution, with Antennariinae found circumglobally and Histiophryninae found in the Indo-Australian Archipelago, and their life history. Members of both subfamilies are primarily benthic but *Histrio histrio* in Antennariinae is exclusively found in floating sargassum seaweed. Frogfishes have enlarged pectoral fins with three elongated pectoral radials and a ball-and-socket joint shoulder which they use to walk, swim, and jet propulsion. However, while both subfamilies are benthic and primarily "walk" when moving around, *H. histrio* lives almost exclusively in floating seaweed and has been noted to primarily "grasp" the seaweed and jet propulse or swim. Has exploiting a non-benthic habitat changed *H. histrio* bone and joint morphology? We examined the bone and joint morphology in the pectoral girdle and fin for 10 species of frogfish using μCT scans of frogfish and 3D reconstruction techniques. Scans were either done by the authors using museum specimens from the ANSP or downloaded from Morphosource. We used 5 species from subfamily Antennariinae, including *H. histrio*, and 5 from subfamily Histiophryninae. All scan data was segmented and measured in Mimics 20.0 software. Despite drastic differences in habitat use, H. histrio has radials that are not significantly different in size or shape when compared to other members of subfamily Antennariinae. In addition, while there is a shape difference in the radials between the two subfamilies, preliminary analysis does not support them being significantly different from one another.

P38-6 Hayer, S; Ewers-Saucedo, C*; Brandis, D; Krause-Kyora, B;

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First insights into extinct oyster diversity

Human impact often leads to the decline or loss of native biodiversity. The European oyster (*Ostrea edulis* L.) is a prominent example for such decline. Abundant and cheap seafood in the past, is the oyster today a sought after delicacy. This change is a consequence of the sharp decline of wild oyster populations in the 20th century. In the North Sea, the European oyster vanished altogether in the 1950s, and has not been able to reclaim its original habitat. What prevents a successful recolonization? Was the original population locally-adapted to the specific North Sea conditions, and oysters from other regions are unable to survive those conditions? Answering these questions requires to travel back in time to investigate a now-extinct population. The Zoological Museum holds the key for such time travel: an extensive collection of oyster shell from all over Europe - including the now extinct North Sea population - collected by Karl-August Möbius around 1870. Using museum genomics, we sequenced over 100 oysters from across Europe that were collected in the 1870s. The North Sea populations show a high degree of unique diversity, which could clearly be responsible for their local extinction.

P38-8 Hayes, JD*; Williams, TM; McDonnell, AJ; Goad, RK; Schuette, S; Martine, CT; Bucknell University, Chicago Botanical Garden, Pennsylvania Natural Heritage Program, Western Pennsylvania Conservancy; *jdh037@bucknell.edu*

Genetic diversity and connectivity of Chasmanthium latifolium (Poaceae) in Pennsylvania: the effect on conservation status

Chasmanthium latifolium (Poaceae) is a rhizomatous perennial plant species that lives in riparian habitats, making it fittingly referred to as river oats. Native to the southern midwest and the eastern half of the United States, *C. latifolium* reaches the northeastern edge of its range in Pennsylvania. *Chasmanthium latifolium* (Poaceae) is comprised of two metapopulations that exhibit an east-west disjunction within Pennsylvania. Due to the limited and isolated distribution of the species within the state and declining populations, *C. latifolium* is considered a critically imperiled (S1) plant in Pennsylvania by the Pennsylvania Natural Heritage Program (PHNP). My study aims to achieve two main

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objectives: 1) survey populations and investigate the genetic diversity and connectivity of the two metapopulations, and 2) revise the conservation status and develop policies to better conserve this species that are scientifically informed. This research uses a genotype-by-sequencing (GBS) approach to generate genomic data for use in population genetics analyses. By employing iPyrad and packages in the R statistical computing software to synthesize these data, I will gain insight into gene flow and the genetic stability of these metapopulations. Ultimately, my research will provide an updated, scientifically-backed conservation status assessment of *C. latifolium* in Pennsylvania. This project will combine rare plant survey protocols from the Pennsylvania Natural Heritage Program and genetic work at Bucknell University to address broad conservation questions.

P5-11 Hayes, HG*; Street, E; Manos, SA; Thompson, N; Schram , JB; Galloway, AWE; University of Oregon, Oregon Institute of Marine Biology, University of Oregon, Oregon Institute of Marine Biology; North Bend High School ; *hannahhayes858@gmail.com*

Does a prolonged exposure to low pH water and low food quality affect juvenile Dungeness crab behavior?

Increases in anthropogenic carbon is contributing to low pH in the ocean, referred to generally as ocean acidification. Low pH water affects the behavior and sensory systems of crustaceans, but little is currently known about the effects of ocean acidification on post-settlement juvenile life history stage in Dungeness crab (*Metacarcinus magister*), particularly their perception of food chemical cues. We captured crab megalopae using a light trap, and settled juvenile crab were maintained in ambient lab conditions on a diet of fresh clam meat until they were second instars prior to placement in the experimental treatments. To understand the foraging and pH sensing behavior of juvenile crabs, and how this interacts with their nutritional status, we exposed recently settled second instar juveniles to either ambient pH or reduced pH for six weeks while providing low and high quality diets to all crabs. After the 6-week experiment, we introduced crabs into a foraging and sensing pH behavior experiment. In the foraging experiment, we placed crabs in a behavior arena with unidirectional flow and a food pellet upstream from the crab, with either ambient

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pH or a reduced pH water flowing through the arena. We measured the food discovery and handling time in 300 second trials. For our sensing pH experiment, we used a two-current choice flume with an ambient pH and a reduced pH, providing a choice between the two, and measured the amount of time individuals spent in each side of the arena in 300 second trials. We hypothesize that crabs from the ambient pH treatment will find food faster, and in the choice trials crabs will spend more time in the ambient pH water.

P4-5 Heide, OA*; Perez, CA; Herrera-Martínez, A; Thomas , R; Daza, JD; Sam Houston State University, Huntsville, TX, University of Missouri, Columbia, MO, University of Puerto Rico, Río Piedras, Puerto Rico; *oah003@shsu.edu*

Smaller, smaller, and smaller

The Puerto Rican Crescent gecko (*Sphaerodactylus nicholsi*) has a disjunct coastal distribution, including North coast and South Coast populations. This is the smallest gecko species from Puerto Rico. Here we measured specimens from both populations and compared measurements (snout to vent length [SVL], and skull length [SL]). Measurements were taken from digital X-rays obtained with a Thermo Scientific™ Micro Focus system and Digital X-Ray Detector using ImageJ. We ran Wilcoxon rank sum test using the North and South populations and found marked differences in SVL (W = 87, p-value = 0.02338) and SL (W = 90, p-value = 0.02787) between the North (Mean SVL=23.38 mm ± 1.95, Mean SL = 6.00 ± 0.26, n=5) and South populations (Mean SVL=20.95 ± 1.39, Mean SL= 5.57 ± 0.36, n=22). Specimens from Punta Verraco are extremely small, being comparable to the smallest amniote (*S. ariasae*) from Isla Beata in Hispaniola. We also review similarities between these miniaturized species, using HRCT data of one individual from *S. nicholsi* and *S. ariasae*. The skull of S. nicholsi is about 1.2 times the size of one of the smallest specimens of S. ariasae. With only 1 mm difference, both skulls look very similar, but *S. nicholsi* has a narrower frontoparietal suture, and proportionally longer jugal bones. *S. ariasae* shows an open prootic foramen (unique to gekkotans). This study indicates that *Sphaerodactylus* geckos from coastal and very dry areas tend to attain record small size. A revision of microhabitat for other miniaturized geckos is needed, and a

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comparison of their cranial anatomy, to determine if the observed traits have evolved multiple times.

P12-1 Herbst, EC*; Bastiaans, D; Miedema, F; Scheyer, TM; Lautenschlager, S; University of Zurich, Zurich, Switzerland, State Museum of Natural History Stuttgart, Germany, University of Birmingham, Birmingham, UK; *eva.herbst@pim.uzh.ch*

How important is modeling tooth enamel in FEA comparisons of whole skulls? Comparing common simplifications with biologically realistic models

Finite element analysis (FEA), in which forces propagate through an object with known material properties, is a useful tool to study the links between form and function. A common application is investigating bite forces and stresses during feeding in extinct and extant animals. In such studies, teeth are usually modeled as a single material with either bone or enamel material properties. However, most animals have teeth composed of an enamel cap covering a dentine layer. Here, using reptiles as a study group, we compare models with a more biologically realistic amount of enamel to those with simplified teeth. We created lower jaw models of the extinct archosauromorph *Macrocnemus bassanii* and herbivorous dinosaur *Erlikosaurus andrewsi*, and the extant monitor lizard *Varanus salvator*. We created three different enamel reconstructions for each taxon, representing the range of relative enamel thickness seen in extant taxa. We compared these more realistic reconstructions with models in which the entire tooth was assigned bone or enamel material properties only. Our results demonstrate the sensitivity of FEA to tooth material properties and reveal in which cases simplifications can be used without significantly affecting model outputs. We further demonstrate a semi-automated method of reconstructing enamel layers that can be applied to future studies. Thickness reconstructions can be adjusted according to estimates using histological information, comparison with modern analogues, or extant phylogenetic bracketing.

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Hedgehog signaling pathway in penaeid shrimp: Developmental expression and evolution of splice junctions

Penaeid shrimp embryos undergo holoblastic division, gastrulation by invagination, and limb bud formation of the first and second antennae and mandibles. Larvae progress through nauplius, protozoea, and mysis stages to postlarvae. Posterior segments form and differentiate during larval development. To study the role of the Hedgehog (Hh) pathway during penaeid shrimp development, gene, RNA, and protein sequences were identified by in silico analysis of genomes and transcriptomes. *Penaeus vannamei*, *P. japonicus*, and *P. monodon* Hh proteins were 526-533 amino acids long, encoded by four exons. The amphipod crustacean *Parhyale hawaiensis* Hh was also encoded by four exons, but *Daphnia magna*, *Drosophila melanogaster*, and *Limulus polyphemus* Hh proteins were encoded by three exons; therefore in malacostracan crustaceans a new splice site evolved in the ancestral Hh Exon 2. *P. vannamei* Patched (Ptc) was encoded by 18 exons, while *Parhyale* Ptc contained 17 exons, both expansions when compared to *Daphnia*, *Drosophila*, and *Limulus*. *P. vannamei* Smoothened (Smo) was encoded by 15 exons, as was *Parhyale*, while *Daphnia*, *Drosophila*, and *Limulus* Smo contained 11, 6, and 12 exons, respectively. The trend shows expansion of exons in all three malacostracan genes of the Hh pathway. *P. vannamei hh*, *ptc*, and *smo* mRNA expression was determined from developmental transcriptomes through postlarvae. Both *hh* and *ptc* showed low expression from zygote to gastrula, increased at limb bud, peaked at unhatched nauplius, and declined in nauplius and later larval stages. *smo* expression was found in zygotes, peaked in gastrula, and declined in limb bud and later stages. These results are consistent with a role for Hh signaling during segmentation in penaeid shrimp.

P41-10 Heslep, NR*; Murphy, AA; O'Hanlon, CP; Wunderlich, RE; James Madison University, Harrisonburg VA; *heslepnr@dukes.jmu.edu*

Validation of collar-mounted inertial sensors for quantifying locomotion in sifakas (Propithecus coquereli)

The use of inertial sensors for quantification of animal behavior and energetics has become commonplace in numerous species. Nevertheless, studies quantifying dynamic body acceleration or locomotor behaviors using inertial sensors in primates are still

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limited, and little attention has been given to methodological concerns such as sensor placement. Device location may influence the calculation of dynamic body accelerations or the classification of behaviors for use in machine learning algorithms for the quantification of positional behavior, particularly in primates who navigate 3-dimensionally-complex environments. Previous studies of primates have typically used back-mounted devices for the quantification of specific locomotor behaviors and collar-behavior. In this study, we compared overall and vector dynamic body acceleration (ODBA and VeDBA), leap counts, and body surface temperature from back-mounted (near center of mass) and collar-mounted inertial sensors (Mbientlab, San Francisco) on *Propithecus coquereli* at the Duke Lemur Center (3.73 hours) and ODBA/VeDBA in a lab simulation. No significant differences in ODBA, VeDBA or leap counts were found between collar and back-mounted devices in the simulation or animal studies ($p>0.05$). Collar-mounted devices exhibited consistently higher temperatures and additional movement signatures related to grooming and communicative displays involving the head. This study demonstrates that collar-mounted devices, which afford greater measurement flexibility (minimal risk of detaching, no interference with infant carrying, longer term placement), are valid and feasible for quantification of dynamic body acceleration and locomotion in primates.

P6-2 Hill, RA*; Lohr, B; University of Maryland, Baltimore County; *rebecc8@umbc.edu*

Grasshopper sparrow warble song: Syllable classification and quantification

Grasshopper sparrow males sing two song types that differ structurally and functionally. While the primary territorial song (the "buzz song") has a relatively stereotyped structure across individuals and populations, the secondary song (the "warble song") is more variable. Songs that contain multiple, repeated elements such as the warble song can differ both phonologically and syntactically between individuals, populations, and subspecies. We visually inspected warble song spectrograms to create a library of syllable types that we will eventually apply to populations across several subspecies of this bird in North America and the Caribbean. We grouped syllables based on acoustic features such as the start

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and end frequencies, number of frequency modulations, total bandwidth, and duration. We successfully implemented a classification scheme for these syllables in populations from several subspecies. We have found that while individuals over a broad geographic range share syllable types, each individual has a unique warble song due to differences in positioning or repetition of these similar elements. This is the first attempt to quantify the structure and possible syntax of the warble song, and it may reveal interesting new distinctions between the songs of different subspecies.

P8-1 Hochberg, R*; Le, A; Mendez, L; Shelley, S; Laudier, D; University of Massachusetts Lowell, MA, Laudier Histology, NY; *rick_hochberg@uml.edu*

Light it up! Cuticular fluorescence in arachnids may be more common than previously thought

A recent hypothesis has suggested that cuticular fluorescence may be plesiomorphic in Chelicerata (Arthropoda) despite its apparent absence from many arachnid lineages based on observations of whole-body (cuticular) fluorescence. Here, we explore the possibility of cuticular fluorescence in species of Acari (Ixodida), Amblypygi, Araneae, Opiliones, Schizomida, and Thelyphonida using resin-embedded, thin section histology and epifluorescence microscopy. We exposed histology sections of whole animals to different wavelengths of light (346 nm (UV), 488 nm, 546 nm) to determine if they fluoresce, and if the fluorescence is of a cuticular or non-cuticular (e.g., hemolymph) origin. We determined that members of most of the above taxa (though not all species) show evidence of cuticular fluorescence under all three wavelengths. Most UV and 488 nm fluorescence appears to be restricted to the exocuticle, though the specific lamina (pigmented or hyaline) that fluoresces will require higher resolution for clarity. Most species also show evidence of fluorescence in their endocuticle when exposed to 546 nm light. The strength of cuticular fluorescence in the different taxa was not quantified, but was concluded to be much lower relative to that of scorpions, which are well known to be strongly fluorescent under UV light. We think the low fluorescence signal of most non-scorpion arachnids explains why UV lamps cannot easily detect them in the dark.

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P36-6 Howell, K*; Richards-Zawacki, CL; University of Pittsburgh; *kih21@pitt.edu*

Could differences in color vision contribute to mate preference divergence in a polymorphic poison frog?

The contribution of sexual selection to speciation is a growing field. In particular, female mate choice has recently been examined as a mechanism for producing divergent mate preferences. However, less attention has been put towards understanding the sensory processes involved in perceiving sexually selected traits and how they may shape mate preferences. Sexual selection by female choice relies on males successfully signaling their fitness to females. If perception of the male's signal varies among females, this could drive divergence in the male signal. Here, I test for differences in color vision between morphs of the color polymorphic poison frog, *Oophaga pumilio*. Females of this frog species generally prefer to court with males of their own color morph. I hypothesize that differences in the opsin proteins responsible for light absorption in the retina of the eye contribute to differences in color-associated mate preferences. To test this, I compare opsin expression levels and opsin sequences among color morphs. My results contribute to understanding how divergent mate preferences are formed, an important step on the path to speciation.

P39-4 Huzar , AK*; Aichelman, HE; Davies, SW; Boston University, Massachusetts; *ahuzar@bu.edu*

Investigating the host buffering hypothesis: How does Breviolum psygmophilum respond to thermal challenge in and out of symbiosis with their coral host, Oculina arbuscula

As ocean temperatures continue to rise, coral bleaching episodes are increasing in frequency, leading to a global decline in coral cover. Previous research has shown that coral hosts exposed to thermal challenges exhibit large shifts in gene expression, while gene expression patterns of their algal symbionts remain comparatively unaffected. This work led us to hypothesize that coral hosts are 'buffering' their symbionts under thermal challenge, which would explain the muted response. Alternatively, the algal symbiont may simply be transcriptomically unresponsive to

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thermal stressors that elicit responses in the host. To test our 'host buffering' hypothesis, *Breviolum psygmophilum* algal cells were isolated from the subtropical scleractinian coral *Oculina arbuscula* and exposed to three temperature treatments: control (maintained at 18° C), heat challenge (heated to 31° C), and cold challenge (cooled to 6° C). After 16 days in temperature ramp treatments, cultures were preserved for transcriptome profiling using TagSeq, which will allow us to characterize gene expression changes in the algal symbiont under thermal challenge in the absence of the coral host. GO enrichment analysis will be used to determine categories of genes that are being differentially regulated, and these patterns will be compared to an existing dataset exploring the response of *B. psygmophilum* while *in hospite* under identical thermal challenges. While data analysis is still ongoing, results of this experiment will provide a clearer understanding of the role of the host in determining how algal symbionts respond to thermal challenges.

P7-3 Jackson, BJ*; Naughton, L; Donatelli, C; Porter, M; Summers, A; Kruppert, S; Idaho State University, Bucknell University, Friday Harbor Laboratories, Florida Atlantic University, University of Washington; *jackbeve@isu.edu*

Body and armor stiffness of the spearnose poacher Agonopsis vulsa (Actinopterygii; Agonidae)

There are 46 species of poachers *(Agonidae)*, and all of them have heavy body armor - protection against predators and aggressive conspecifics. But the protection of armor should come at a cost. We hypothesized that poachers pay for their armor in reduced maneuverability and increased body stiffness. To test our hypothesis, we recorded the natural flexibility of the Northern Spearnose Poacher *(Agonopsis vulsa)*, by analyzing videos of its flight response, and found that the fish are quite flexible. We also used dead specimens in bending experiments to determine the body stiffness. The fish were bent in three different states (intact, with the plates removed, and with the muscle removed so that only the vertebral column remained) to quantify the contributions of each layer to whole body stiffness. To quantify the protection gained from the armor, we looked at the material properties (stiffness) of the plates. We used material testing to

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determine a stiffness parameter and compared it to vertebral bone from the same specimens. We found no difference in stiffness between plates and bones. While the plates do contribute to stiffness in the fish, the extent is not as pronounced as expected. In addition, they contribute much more heavily to the stiffness of the body region than the tail region.

P36-1 Jalala, HM*; Awad, AH; Murray, JA; Cain, SD; California State University East Bay, Eastern Oregon University; *james.murray@csueastbay.edu*

Magneto-sensory orientation discrepancies across different populations of the sea slug Tritonia when undergoing magnetic field rotations

One population of the nudibranch *Tritonia tetraquetra* (a.k.a. *Tritonia diomedea*) has proven to orient to the geomagnetic field of the earth. We tested the magnetic sense in another population to see if they would behaviorally and neurologically react to rotations of the magnetic field. This was done by observing sea slugs crawling freely surrounded by a 4 square "Merritt coil". This allowed us to change the direction of the magnetic field inside the cube. We predicted the flipping the magnetic field 180° (so North feels like South) would cause slugs to orient 180° of what was observed under the normal geomagnetic field. We found no significant orientation in the normal field, and no difference in orientation between normal and reversed field over 31 trials in 4 slugs (from a population near Dash Point, WA). Previous results in a population of this species from Bellingham Bay showed a corresponding turn to a 180° rotation of the magnetic field, and our negative results might be explained because we used a different population that lacks this sensory ability. Or if this population does have a magnetic sense, our experimental design differences may account for the lack of observed orientation. In addition to experimenting with turning behavior, we also recorded from specific brain neurons (Pd3) that were previously shown to cause the slug to turn upstream. When flipping the magnetic field, we predicted that both the left and right turning neurons should alter their firing/response rate after flipping the field. Recordings from pedal ganglion flexion neurons show no obvious changes in activity during or after magnetic rotations.

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P37-6 Janisch, J*; Quigley, C; Perinot, E; Fusani, L; University of Veterinary Medicine, Vienna, University of Vienna; *Judith.Janisch@vetmeduni.ac.at*

3D-motion capture to analyse a complex courtship display

Recently, several studies focused on the analysis of animal movements in three dimensions for a better understanding of behaviour or biomechanics using 3D motion capture systems. In laboratory settings, with standardized procedures and fixed lighting sources this works very well by now. In contrast, 3D field recordings are still very challenging due to constant environmental changes or the inability to use markers on the focal individuals. Amongst the most complex behaviours is the elaborate courtship dance of golden-collared manakins *Manacus vitellinus*. In their lek mating system, males compete over females in so-called courtship arenas located on the forest ground to perform their dances. As their courtship display can only be recorded in their natural habitat and happens on a short time-scale, researchers only recently started to understand and describe their behaviour in more detail thanks to advances in video recording technology. With a newly developed 3D-high speed recording system for the field and an image processing system including automated tracking software we acquired the 3D coordinates of our birds' movements. Through further analysis of these 3D coordinates we obtained better knowledge about the differences between males' performances also related to the spatial arrangement of their arenas, their dance choreographies and their courtship success. The successive analysis allows us to get closer to the goal of our research, which is the understanding of the mechanisms underlying female choice and to see if there is an overall integrative value of all components of male dances used by females to evaluate a mate.

P33-3 Jeradi, S*; Franz-Odendaal, TA; Mount Saint Vincent University; *shirine.jeradi@msvu.ca*

Evaluating the effects of whole-body vibrations (WBV) on vertebrate bone development using zebrafish larvae as a model

Whole-body vibrations (WBV) are a potentially harmful non-chemical pollutant that can have severe effects on developing embryos,

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especially during the first semester of pregnancy, when organisms are most susceptible to defects and abnormalities. In this study, we established the zebrafish as a laboratory-based animal model to provide an in-depth evaluation of the effect of exposure to WBV on the bone tissue of a living organism, during bone development. Zebrafish embryos and larvae were exposed to low-frequency WBV, ranging between 10 and 20Hz, for up to 4 days. Despite their mildness, these treatments were sufficient to induce a wide array of skeletal defects in zebrafish larvae. Depending on the developmental stage at which the exposure to WBV was started (from 10 hours post-fertilization to 5 days post-fertilization), the skeletal elements of zebrafish larvae were affected differently. The observed phenotypes ranged from missing bone elements to bone fusions, and varied depending on the type of bone that was affected. These results indicate that exposure to WBV during embryonic development can affect the normal skeletal development in vertebrates.

P19-4 Johanson, Z*; Manzanares , E; Underwood, C; Clark , B; Fernandez, V; Smith, MM; Natural History Museum, London, University of Valencia, Valencia, Birkbeck University, London, King's College London, London; *z.johanson@nhm.ac.uk*

Ontogenetic development of the holocephalan dentition: Morphological transitions of dentine in the absence of teeth

The dentition of extant holocephalans (chimaeroids; Chondrichthyes) differs from other chondrichthyans (sharks, rays), in that teeth are absent. Instead, holocephalans bear dental plates composed entirely of dentine, notably a hypermineralized form made of whitlockin, restricted to pre-formed spaces within trabecular dentine. Whitlockin is deposited without a fibrous matrix and develops into a variety of morphologies, becoming increasingly mineralized, and more wear-resistant than the supporting dentine. This creates surface morphologies important in differentiating extant and fossil species. These morphologies include separate rods and ovoids, and compact tritoral pads with a distinctive pattern of vascular canals. This ability to make dentine is retained in the evolution of the Holocephali, but with a new mineralogy, and into these specific patterns. Successive growth stages of the dentine-retaining plates demonstrate developmental continuity between these

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morphologies, the earliest being the rod-shaped whitlockin. As these lingual rods grow, vascular grooves form, as dentine surrounds associated blood vessels; these are eventually aligned spatially to form the morphology of the tritoral pad. Later, along the lateral margin of the dental plate, rods are replaced by a series of ovoids. We propose that the different shapes of these whitlockin entities are developmentally linked, transformed from pre-formed cellular, vascularised spaces of trabecular dentine through to their adult morphologies. This indicates patterning of whitlockin within the dental plate and of the surrounding dentine, with the ability of the latter to change substantially to accommodate these developmental changes.

P40-3 Johansson, LC*; Henningsson, P; Lund University; *Christoffer.Johansson@biol.lu.se*

Butterfly flight reveals efficient propulsive clap mechanism

Butterflies display a range of flight behaviors, from fluttering flight to long distance directed migration. Butterflies also look like no other flying animal, with unusually large and broad wings relative to their body size. Wing shape influence aerodynamics and butterflies have been suggested to use almost any aerodynamic trick in the book to boost flight performance. However, quantitative measurements of the aerodynamics of free flying butterflies are lacking. Here we present direct measurements of the forces, from particle image velocimetry, generated during take-off flights in Silver-washed fritillary (Argynnis paphia). We find that the butterflies use upstroke wing claps to thrust themselves forwards while the downstroke provides the majority of the vertical force. We also suggest a mechanism for effective and efficient wing claps, using flexible wings, which we test using a robotic clapper. Together our findings suggest butterflies evolved an efficient wing clap, which may explain their unusual wing morphology.

P30-3 Johnson, HC*; Wilsterman, K; Good, JM; Cheviron, ZA; University of Montana; *Hannah8.Johnson@umontana.edu*

Does adaptation to high altitude affect hypoxia-dependent structural plasticity of the placenta?

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High altitude residence causes fetal growth restriction (FGR) during pregnancy in lowland mammals. Highland-adapted mammals do not experience this altitude-dependent FGR, suggesting that evolutionary adaptation has provided some physiological protection. However, the specific mechanisms by which highland-adapted mammals preserve fetal growth at altitude remain unknown. We hypothesized that highland-adapted populations protect fetal growth through structural changes to the placenta that increase surface area for maternal-fetal nutrient and gas exchange. We tested this hypothesis using deer mice (*Peromyscus maniculatus*), from populations native to low [400 m, Lincoln, NE] and high [4300 m, Mt. Evans, CO] altitudes. We predicted structural adaptation would occur via increases to the relative size of the labyrinth zone (LZ), the layer within the rodent placenta where nutrient and gas exchange occur. Placentas were collected from lowland and highland deer mice undergoing pregnancy under normobaria or hypobaria (60 kPa) to understand how hypoxia-dependent structural plasticity might interact with adaptive remodeling of the placenta (N = 5-7 per strain and treatment). Using immunohistochemistry, we quantified the size of each placental zone. Our preliminary results showed that highlanders have relatively larger placental arteries and LZs under both normobaria and hypobaria ($P < 0.05$ in generalized linear mixed models), suggesting that blood delivery and area for exchange (as determined by the LZ size) may protect fetal growth in highlanders. Future work will pair histological characterization of placental structure with transcriptomics to guide a mechanistic understanding of how placentation constrains fetal growth under hypoxia.

P40-10 Johnson, ML*; Danos, N; Butler , MA; University of San Diego, University of San Diego , University of Hawaii; *maxwelljohnson@sandiego.edu*

Swimming functional morphology and performance in five ecomorphs of the direct developing Microhylidae

The transition from aquatic to terrestrial lifestyle provides anurans the opportunity to occupy different ecological niches. The direct developing Microhylidae are a speciose family of frogs that has diversified ecologically into five ecomorphs: terrestrial, arboreal, scansorial, fossorial, and secondarily aquatic. The

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adaptive radiation of the microhylid family provides an opportunity to test the relationship between form and function in a highly specialized Anuran body plan. Six species, representing all five ecomorphs, were collected in Papua New Guinea and filmed in the field swimming at 30 fps. We quantified the hindlimb kinematics and calculated hydrodynamic force production to compare swimming performance in the six species. We hypothesized that the secondarily aquatic ecomorph *(Austrochaperina palmipes)* would swim faster, stronger and more efficiently than the terrestrial ecomorphs, even though it arose from a fully terrestrial ancestor. Center of mass velocity, stroke displacement, and swimming efficiency, as measured by the foot slip, were all significantly higher in the aquatic ecomorph. However, a terrestrial ecomorph *(Mantophryne lateralis)* had significantly larger propulsive impulse than the aquatic ecomorph. Additionally, of the terrestrial ecomorphs, the jumpers performed better than the arboreal, scansorial, and fossorial ecomorphs in terms of COM velocity, propulsive impulse, effective foot velocity, and stroke displacement. These results support the hypothesis that adaptation to ecological niches is driving performance.

P33-12 Johnson, T*; Katugam, K; Dechene, I; Cox, SM; Piazza, SJ; Rubenson, J; The Pennsylvania State University, The Pennsylvania State University and The University of California, Irvine; *jonas@psu.edu*

Develpmental plasticity of locomotor economy in guinea fowl

Whether adaptations in locomotor economy occur across an individual's life span remains unclear. To understand better the scope of developmental plasticity of locomotor economy, we increasing distal limb mass experimentally by a factor of ~ 3x over the maturation period in growing guinea fowl. At 1 wk, animals were assigned to a control group (CON, n=6) and an experimental group (EXP, n=6) with a mass equal to 3.75% of the individual's body mass chronically added to the right leg throughout growth. We hypothesized that the EXE group would be more economical at carrying extra limb mass compared to the CON group. We also hypothesized that the EXE group would have a worse economy when walking unloaded compared to CON. At 16 wks of age, a flow-through metabolic system was used to measure metabolic power during

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treadmill walking at 0.5 m/s. In agreement with our first hypothesis, average net metabolic power in the limb-loaded condition was on average 26% lower in the EXP group (3.9 +- 0.5 W/kg) compared to the CON group (5.3 +- 1.1 W/kg) ($p = 0.03$). However, contrary to our second hypothesis, the net metabolic power was not different between the EXE and CON in the unloaded condition. Surprisingly, metabolic power was also not different between the loaded and unloaded condition in the EXE group, despite the presumably large reduction in mechanical work associated with lifting and accelerating the limb after removing the mass. These preliminary data suggest that locomotor economy may be affected by loading history during growth and may be tuned to the animal's habitual loading environment. Supported through NIH Grant R21AR071588.

P31-2 Jones, KR*; Belden, LK; Hughey, MC; Virginia Tech, Blacksburg, Virginia, Vassar College, Poughkeepsie, New York, USA; *korinrex@gmail.com*

Exposing frog embryos to bacterial isolates: Colonization order impacts structure of the tadpole microbiome

Dispersal and colonization are stochastic processes that can impact assembly of ecological communities. Colonization order, often referred to as priority effects, can leave a lasting impact on community composition through time. Embryos that develop in an external environment, such as those of amphibians, experience stochasticity in the arrival order of bacterial colonists. We sought to determine if priority effects during embryo colonization impacted bacterial community composition on newly hatched tadpoles. To answer this question, we selectively inoculated the embryos of lab-raised hourglass tree frogs, *Dendropsophus ebraccatus*, over two days with two bacteria (Genera: *Acinetobacter* and *Stenotrophomonas*) initially isolated from the skin of wild adult *D. ebraccatus* in Panama. On day one, each egg received an inoculation of one of our chosen isolates or sterile water. On the second day, eggs received either the same isolate, the alternate isolate, or sterile water. By altering the order in which isolates were received, we hoped to elucidate the impact of priority effects on resulting tadpole bacterial communities. Through 16S rRNA gene amplicon sequencing, we observed shifts in the relative abundances of ASVs within the

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tadpole communities due to priority effects. For the *Acinetobacter* isolate, the effect of being the first inoculum led to increased relative abundance, which was not the case when the *Stenotrophomonas* isolate was first. In addition, we observed differences in community composition as a result of our varied treatments. Our results suggest that the initial environmental conditions that embryos are exposed to shape microbial communities at later life stages; however, stochasticity in colonization does not impact all potential colonists in an equal manner.

P26-5 Kaatz, IM; SUNY ESF Syracuse NY I am retired; *imkaatz@yahoo.com*

Are the behaviors of the domestic cat (Felis catus) predominantly domesticated or feral/ancestral? A hypothetical evaluation of temperament and personality traits

While volunteering for Friends of Felines, Inc., Stamford, CT 2008 - 2020 socializing rescue cats for adoption I documented behaviors of individual cats that were destined for indoor home adoption and established a behavioral repertoire. Cats were surrendered or caught in traps outdoors and housed under similar care conditions. Cages typically were multiple cubicles or levels and when possible individuals interacted with other cats in a common play space. Data consisted of written observations during cat visits, photographs and video. Age classes were pooled for juveniles and adults. Observations were for one or more weekly visits per cat. The behavioral repertoire consists of 395 traits for: human social interactions; cat-cat interactions; individual cat displays, cognitive skills or activity level. Nine rescue personalities (41+19SD traits/rescue personality) are examined to determine their robustness as behavioral syndromes: Wildthing (feral hard-wired traits), Warrior (aggression), Tribble (human affection), Laplander (human tactile companion), Homebody (small home range), Olympian (high agility & motion), Rockstar (vocally active), Explorer (intelligence and curiosity) and Toy Enthusiast (co-opted prey hunting behaviors). Temperaments assessed on arrival during the first visit were people (n = 541 #cats): friendly (295, 55%); shy (176, 33%); and aggressive (70, 13%). A hypothetical evaluation of these cat types and their representative behavior traits as either domesticated or ancestral is discussed.

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P33-9 Kabutz, HD*; Jayaram, K; University of Colorado Boulder; *heiko.kabutz@colorado.edu*

Morphological compliant robotic system in cluttered terrain

The remarkable ability of animals, such as mice, cockroaches and spiders, to manoeuvre through challenging cluttered natural terrain has been a primary inspiration for legged robots. Recent research indicates that body reorientation along pathways of minimal energy is a key factor influencing such locomotion. We propose to extend this idea by hypothesizing that soft bodied animals and robots could employ an alternate yet equally effective strategy relying on their distributed body compliance to squeeze through cluttered obstacles. To demonstrate the same, we have developed a palm-scale, origami-based hexapedal robot, Compliant Legged Articulated Robotic Insect (CLARI) with compliant exoskeletal morphology. The robot, fabricated using a multilayer laminate laser micromachining technique, has six independently servo motor actuated two degree of freedom legs that are steered with the use of swerve drive concepts from wheeled robotics. Using this strategy, CLARI is able to passively conform to its environment and move through both horizontally and vertically confined spaces and requires only simple leg mechanics. We aim to verify our hypothesis by constructing a series of robots with varying body compliance and experimentally determining the preference for body deformation vs reorientation in a given cluttered environment for identical feedforward control commands.

P1-1 Kaley, S*; Krohmer, RW; Saint Xavier University; *sarahkaley@ymail.com*

Examination of c-fos activity in the brain of male red-sided garter snakes following exposure to the female pheromone

C-Fos, an early intermediate gene, is a protein that can be used as an indicator of genetic mechanisms in neurons. Studies in many vertebrates have linked the production of C-Fos to the regulation of courtship and mating behavior. However, little is known about these proteins in relation to reptilian behavior. In our study, C-Fos expression was observed in the brains of male Red-Sided Garter snakes following exposure to the female sex attractant pheromone at

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different intervals ranging from 0 minutes to 45 minutes revealing a specific window of activation.

P12-10 Kamau-Weng, J*; Farina, S; Northeastern University, Howard University; *kamau-weng.j@northeastern.edu*

Ventilatory pressures generated by gill chambers of the chimaera Hydrolagus colliei

The spotted ratfish, *Hydrolagus colliei*, is a functional intermediate between sharks with gill slits and teleosts with a bony operculum. The ratfish possesses a single gill chamber on either side of its head, bounded by a fleshy opercular flap with a single opening for each chamber located on the underside of the head. Previous studies have reported extremely low ventilation amplitudes consisting of 13-16Pa from the gill chambers of the ratfish. This investigation seeks to further characterize the ventilatory characteristics and patterns from the gill chambers of the ratfish. In addition, this study also seeks to determine if a positive relationship between body size and ventilation amplitude exists. Ventilation pressures were measured from the right gill chamber using implanted pressure transducers. Behavioral observations and amplitude patterns were combined to categorize the pressures into three distinct categories: active, quiet and recovery. Amplitudes recorded in this study were larger than those previously reported with sampled amplitudes averaging around 43Pa and ranging from 21Pa - 78Pa. Due to the close evolutionary relationship between Holocephalans and Elasmobranchs, ventilation amplitudes were predicted to increase with size as seen in a close elasmobranch relative *Squalus acanthias*. However, smaller ratfish produced amplitudes larger than those produced by larger ratfish which was the opposite of what was observed in *Squalus acanthias*. Ventilation amplitudes obtained in this study exemplify that the spotted ratfish is capable of generating both low pressures and relatively high pressures in their gill chambers.

P19-3 Kang, KJ*; Nash, CM; George, AB; Westneat, MW; University of Chicago, Field Museum of Natural History; *kkang1@uchicago.edu*

Comparative biogeography and geometric morphometrics of the balistoid fishes

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Understanding relationships between geographic distribution and morphological diversity of a taxonomic group can provide key insights into the evolutionary and ecological history of marine communities. Fishes in the superfamily Balistoidea provide an ideal system in which to examine these relationships because they inhabit tropical to subtropical waters of the Atlantic, Pacific, and Indian Oceans and display a large amount of morphological and functional diversity. The superfamily Balistoidea contains 151 species in two families, the filefishes (Monacanthidae) and the triggerfishes (Balistidae). Our main questions in this study were 1) what are the evolutionary relationships among species within and among each balistoid community, 2) how are morphologies distributed across marine communities, and 3) what is the role of morphological evolution in maintaining community dynamics? We hypothesized that more closely related species and species exhibiting similar morphologies will form distinct communities, which may indicate their ability to coexist in similar regions. We inferred communities of the Balistoidea based on the degree of species turnover. Using clade-specific communities as a framework, we analyzed the relationships among geographic distribution, community composition, phylogenetic diversity, and morphometrics of these species. We used geometric morphometrics to examine patterns of diversity in body shape and fin shape within and among marine communities. We found significantly different evolutionary and morphological dynamics within and among marine communities both regionally and globally. Distinct differences in the distribution of morphotypes across communities reveals the important role that morphological diversity plays in understanding the evolutionary history of species and how it shapes ecological community dynamics.
NSF DEB-1541547

P10-11 Kang, KJ*; Nash, CM; George, AB; Westneat, MW; University of Chicago, Field Museum of Natural History; *kkang1@uchicago.edu*
Comparative biogeography and geometric morphometrics of the balistoid fishes
Understanding relationships between geographic distribution and morphological diversity of a taxonomic group can provide key insights into the evolutionary and ecological history of marine communities. Fishes in the superfamily Balistoidea provide an ideal

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system in which to examine these relationships because they inhabit tropical to subtropical waters of the Atlantic, Pacific, and Indian Oceans and display a large amount of morphological and functional diversity. The superfamily Balistoidea contains 151 species in two families, the filefishes (Monacanthidae) and the triggerfishes (Balistidae). Our main questions in this study were 1) what are the evolutionary relationships among species within and among each balistoid community, 2) how are morphologies distributed across marine communities, and 3) what is the role of morphological evolution in maintaining community dynamics? We hypothesized that more closely related species and species exhibiting similar morphologies will form distinct communities, which may indicate their ability to coexist in similar regions. We inferred communities of the Balistoidea based on the degree of species turnover. Using clade-specific communities as a framework, we analyzed the relationships among geographic distribution, community composition, phylogenetic diversity, and morphometrics of these species. We used geometric morphometrics to examine patterns of diversity in body shape and fin shape within and among marine communities. We found significantly different evolutionary and morphological dynamics within and among marine communities both regionally and globally. Distinct differences in the distribution of morphotypes across communities reveals the important role that morphological diversity plays in understanding the evolutionary history of species and how it shapes ecological community dynamics.
NSF DEB-1541547

P7-2 Karkosiak, KQ*; Coonfield, AJ; Ediriweera, CU; Maksuta, DD; Blackledge, TA; University of Akron; *kqk2@zips.uakron.edu*

Are spider egg sacs extra hydrophobic?

Spiders construct egg sacs to protect their eggs from predators and maintain an appropriate internal environment for development. Egg sacs are produced using a variety of silk types. The outermost layer is often composed of tubuliform silk, which is unique to egg sacs and is only produced by mature female spiders. Tubuliform silk has a distinct amino acid composition and mechanical properties compared to major ampullate silk. By comparing the wettability, via contact angle measurement, of tubuliform and major ampullate silk with known amino acid sequence composition, we test the hypothesis

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that tubuliform silk may be specialized to maintain internal conditions of egg sacs, particularly by excluding bulk water from rain or dew from entering the sac and drowning the eggs. We assessed the variation of surface hydrophobicity of the egg sacs and major ampullate silk samples of *Argiope trifasciata*, *Latrodectus hesperus*, *Larinioides cornutus*, and *Parasteatoda tepidariorum* by contact angle determination to test the prediction that the outer surfaces of egg sacs would be more hydrophobic. In addition, we selected species with available amino acid sequences for both major ampullate spidroin (MaSp) and tubuliform spidroin (TuSp) proteins for sequence comparison, and compared the density of hydrophilic and hydrophobic amino acids to test the prediction that tubuliform silks contain more hydrophobic domains. Our findings play a key role in determining the underlying mechanisms by which 1) egg sacs maintain appropriate conditions for development and 2) tubuliform silk may have become specialized from more ancestral silk types.

P41-4 Katugam, K*; Johnson, T; Dechene, I; Cox, SM; Piazza, SJ; Rubenson, J; The Pennsylvania State University, State College, PA; *kxk751@psu.edu*

Developmental plasticity of walking energetics and swing-phase mechanics in chronically limb-loaded fowl

How locomotor mechanics and energetics are affected by long-term alterations to external loading during growth remains largely unknown. Here we test the hypothesis that a reduction in mechanical limb work contributes to a lower cost of carrying externally-applied limb mass after chronic loading. To test this, we applied a mass equal to 3.75% body mass unilaterally to the lower limb of a group of guinea fowl continuously from 1-16 wks of age (EXP group; n = 6). We raised a second group of birds in the same conditions but with no external limb loading (CON group; n = 6). At 16 wks of age we measured the metabolic cost of walking (CoT) on a treadmill at 0.5 m/s in both unilaterally-loaded and non-loaded conditions. We used an inverse dynamic procedure to compute pelvic limb joint powers and work during the swing phase of walking from motion capture (100 Hz). The mass-specific CoT of unilateral limb loading was 34% greater in the CON group compared to the EXP group (p = 0.03). Surprisingly, the CoT in the habitual condition (limb loaded

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in EXP; unloaded in CON) was the same for both groups, despite the EXP group moving substantially more limb mass. Preliminary data indicate that animals subjected to increased limb loading across their growth period exhibit lower mass-specific mechanical joint work during limb swing. However, it is unlikely that mechanical work alone can explain the markedly lower cost of carrying external limb mass in the EXP group. We aim to further understand the determinants of the lower energy cost of carrying mass in EXP including the extent by which this is achieved by locomotor kinematic plasticity, adaptations to musculoskeletal morphology and/or physiology.

P9-11 Keating, SE*; Pinto, B; Gamble, T; Marquette University; *skeating63@gmail.com*

Dosage balance of the crested gecko (Correlophus ciliatus) ZZ/ZW sex chromosomes

Sex chromosomes evolve from an ancestral chromosome pair that acquires a sex-determining locus. The sex-determining locus will become linked to a sexually antagonistic allele through recombination suppression, preventing the proto-sex chromosomes from repairing DNA and allow mutations to accumulate. Over time, the sex-limited chromosome (W chromosome in ZZ/ZW systems) will begin to degenerate and lose genes, leaving Z-linked genes hemizygous in the heterogametic sex (females). If the halved gene dose lowers average female expression levels, dosage balance will be lost as males and females will no longer have equal average expression levels on the sex chromosomes. However, there is a dearth of studies on the presence or absence of dosage balance in certain organisms, such as squamates lizards, and more work is needed to understand whether gene expression must be balanced between the sexes. Here, I use RNAseq data to examine dosage balance on the Z chromosome of the crested gecko, *Correlophus ciliatus*. I examine the female:male expression ratio of autosomal and sex-linked genes and show that female and male expression is equal except for hemizygous Z-linked gene, in which the W gametolog is no longer expressed. Thus, when genes are lost from the W chromosome, Z-linked genes do not appear to be upregulated in females relative to males. This demonstration of the lack of dosage

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balance within a gecko species contributes to our growing knowledge on sex chromosome degeneration and gene loss.

P18-7 Kenwood, MR*; Fuchs, ME; Ursinus College, Department of Biology, Collegeville PA; *makenwood@ursinus.edu*

Is pollution driving evolution: Killifish adaptability

Various populations of *F. heteroclitus*, a common killifish, suffer from devastating heart defects due to pollutants such as polychlorinated biphenyls (PCBs) and other Poly Aromatic Hydrocarbons (PAHs). *F. heteroclitus* from highly polluted populations in Massachusetts have evolved resistance to these pollutants, avoiding heart defects. Resistance has been hypothesized to occur in one of the two Aryl Hydrocarbon Receptors (AHR 1/2), a protein that brings the pollutants into the fish's cells acting as a transcription factor for the Cytochrome P450 family of enzymes. Exon 10 of AHR1 contains several non-synonymous mutations that have been thought to contribute to resistance.
The *F. heteroclitus* born in Darby Creek coursing through the John Heinz National Wildlife Refuge, Philadelphia, PA develop downstream from two EPA Superfund sites that leach PCBs and other contaminants into the Darby Creek. Through single nucleotide polymorphism (SNP) and direct sequence analyses of the mitochondrial DNA control region we determine whether the Heinz population, a nearby control population, and a coastal population consist of exclusively the northern or southern subspecies or a mixture of both as pollution responses may differ between subspecies. We are examining exon 10 of the AHR1 gene in all three populations to determine if nonsynonymous mutations have occurred, potentially conferring pollution resistance. Preliminary analysis reveals AHR1 exon 10 sequence differences among populations. Through identifying and studying *F. heteroclitus*, we investigate how pollution may be driving evolution.

P21-11 Khoriaty, M*; Kane, E; Bowdoin College, University of Louisiana at Lafayette; *mkhoriat@bowdoin.edu*

Jaw morphology in Poecilia reticulata does not differ in high- and low- predation environments

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Environmental variations can lead to changes in morphology, which in turn affect performance, or how an animal can use these structures. For example, exposure to predation has the capacity to influence many aspects of prey form and function to facilitate survival. *Poecilia reticulata*, Trinidadian guppies, live in both high- and low- predation environments, which are separated by waterfalls, and resulting predation-driven differences in jaw structures, consumption rates, and trophic status have been demonstrated. However, divergence has not been supported in kinematic performance of prey capture, making the links between structural and functional divergence unclear. Jaws were previously examined only from a dorsal view, but feeding uses movement in multiple planes, and viewing specimens from additional views may provide more insight to the potential for ecological divergence of feeding mechanics. Using CT scans of individuals from contrasting populations, I measured lengths of various functionally relevant bones in the jaw from dorsal, lateral, and ventral views. I used general linear models accounting for size differences between the fish and found that predation level did not affect functional jaw morphology. In this species, trophic differences are observed in the absence of corresponding morphological changes, and changes in prey capture due to predation are likely driven by other traits, such as behaviors.

P30-1 Khudyakov, J*; Holser, R; Ly, S; Niel, T; Banerjee, R; Hasan, B; Nguyen, KD; Tan, E; Tang, C; Vierra, C; Costa, D; University of the Pacific, University of California, Santa Cruz; *jkhudyakov@pacific.edu*

Multi-tissue proteome responses to prolonged fasting in a capital breeding marine mammal

Capital breeding marine mammals such as northern elephant seals are uniquely adapted to tolerate prolonged fasting periods associated with terrestrial reproduction and molting. We used a proteomics approach to gain insights into cellular mechanisms of energy provisioning during fasting in elephant seals. We collected blood, blubber, and muscle from adult female elephant seals at the beginning and end of a month-long molting fast and compared protein expression between samples using label-free protein quantification by LC-MS/MS. We identified 309 proteins in plasma, 743 proteins in

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muscle, and 1098 proteins in blubber. Fifty proteins were differentially expressed in plasma, while only two proteins were differentially expressed in both muscle and blubber between early and late fasting stages. Apolipoprotein A-IV was significantly downregulated in all three tissues in late compared to early fasting. Proteins upregulated over fasting in plasma included corticosteroid-binding globulin, zinc-alpha-2-glycoprotein, and angiotensinogen, while ferritin was the only protein upregulated in muscle. Proteins downregulated in plasma included alpha-2-macroglobulin and apolipoprotein E, which was also downregulated in blubber. Changes in protein expression were consistent with high levels of lipolysis and endogenous glucose production, insulin resistance, and cortisol elevation observed in fasting seals. These data suggest that the proteomes of energy-utilizing and energy-provisioning tissues remain remarkably stable during periods of high energy expenditure coupled with food deprivation in a fasting-adapted mammal.

P9-6 Kim, C*; Kültz, D; Universitiy of California, Davis, UC Davis; *cshkim@ucdavis.edu*

A modified CRISPR system for transcriptional activation of tilapia endogenous genes

Recently, the CRISPR system has been repurposed for endogenous gene activation or repression by introducing a catalytically inactive form of Cas9 (dCas9) followed by fusions of the dCas9 to effector domains such as VP64 (activation), p300 (activation + epigenome editing) and KRAB (repression). This modified CRISPR system provides a simple and versatile tool for RNA-guided manipulation of endogenous gene expression. As a proof of principle for this system in a fish model we focused on developing CRISPR activation (CRISPRa) in the tilapia (Oreochromis mossambicus) OmB cell line to implement this promising approach. Building upon our previous CRISPR optimization with two different tilapia endogenous promoters used in both Cas9 and gRNA expression plasmids, the original Cas9 part in the plasmid was replaced by dCas9 (D10A, H840A) and the tilapia p300core. The p300core-mediated CRISPRa can target the specific promoter or even enhancer regions of a gene of interest due to the chromatin state modification ability of p300 which has histone acetyltransferase activity. The tilapia inositol

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monophosphatase 1 gene (IMPA1.1) and its promoter region were selected as target gene and gRNA target region, respectively. By targeting the IMPA1.1 promoter region (400 bp) using 6 different gRNAs with transient transfection of OmB cells, three gRNAs showed an increase in IMPA1.1. promoter-driven luciferase reporter expression and in mRNA levels of IMPA1.1 by 4- to 6-fold in regular medium. These results indicate that the p300-CRISPRa system enables efficient target gene activation with appropriate target-specific gRNAs in tilapia cells. To control for off-target effects in analyzing IMPA1.1-dependent phenotypes, non-target gRNAs will be used. This work provides the basis for quantitative proteomics to track changes in molecular phenotypes in response to targeted IMPA1.1 gene transcriptional activation and resulting cellular phenotypes.

P7-6 Kim, B*; Orlovic, I; Yee, R; He, Y; Waldrop, LD; Chapman University, University of North Texas; *waldrop@chapman.edu*

Circulatory resistivity increases costs of circulatory transport in peristaltic systems

Peristalsis represents one way that animals can drive circulatory flow. Tubular hearts that drive flow peristaltically are present in many invertebrate circulatory systems, as well as early embryonic vertebrates. Although peristalsis is a well-studied system in many contexts, very few studies have examined the performance of peristaltic systems with different resistive circulatory systems. In this study, we examine the performance of peristaltic hearts with circulatory systems of various resistance through a computational fluid dynamics modeling. Two peristaltic mechanisms were used, opposing sine waves and opposing sharp Gaussian peaks, which allowed for investigating the role of heart tube flexibility. We found that increasing circulatory resistivity decrease flow rates and greatly increased the cost of transport. Additionally, flexibility of the heart tube allowed for greater flow speeds within the circulatory system and more consistent flows in additional resistivity. This provides potential insight into the action and physical limits of peristaltic pumps in terms of driving flow in resistive circulatory systems.

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P22-1 Kleckner, K*; Zlotnik, S; Miller, CW; University of Florida; *kaylin.kleckner@gmail.com*

Behavioral strategies of juveniles: Attraction to adult feeding cues

Juvenile animals are often less adept at feeding independently compared to their adult counterparts. To obtain critical nutrients, juveniles may use behavioral strategies that make up for morphological limitations, but such strategies are not well understood. We hypothesized that juveniles prefer food sources on which an adult has previously fed because prior feeding damage may make nutrients more accessible. We tested this hypothesis in leaf-footed cactus bugs, *Narnia femorata* (Hemiptera: Coreidae). These insects feed on cactus fruit, but juveniles are less efficient due to their shorter mouthparts. In our behavioral experiments, juvenile *N. femorata* chose between two fruits: one had been fed on by an adult for one week, while the other had experienced no adult contact within the preceding six weeks. As predicted, juvenile insects preferred to stand and feed on the adult-fed fruit over the control fruit. This preference was maintained over a three-day period. Our results suggest that juvenile *N. femorata* maximize nutrient intake by taking advantage of the feeding damage created by adults or by using adult cues to identify reliable food sources. This study provides insight into behavioral strategies used by juvenile animals to maximize survival in harsh environments.

P19-1 Knapp, A*; Rangel, G; Johanson, Z; Giles, S; Friedman, M; Goswami, A; The Natural History Museum, London, University of Birmingham, University of Michigan; *a.knapp@nhm.ac.uk*

How to tuna fish: Drivers of diversity in Pelagiaria (tunas, mackerels and their kin)

Teleost fishes represent the most taxonomically diverse group of living vertebrates, and occupy a vast range of ecological niches. Morphological diversity is particularly notable in the skull. Understanding how this diversity has evolved in the ~250 million year history of teleosts presents a challenge because of the complex three-dimensional structure of the teleost skull and the number of species involved. Modularity, or the division of complex structures such as the skull into a smaller number of integrated, independent units known as modules, provides a solution to this

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problem. The skulls of many tetrapod clades have been shown to be highly modular but, most fish studies have focused on the neurocranium or overall body form. Here we present an analysis of skull modularity in ~50 species of the morphologically diverse but numerically tractable teleost group Pelagiaria. Using three-dimensional geometric morphometrics, our analysis encompasses the neurocranium, jaws and operculum, enabling an analysis of morphological diversity across the entire skull and allowing a more direct comparison to previous tetrapod studies. Our results show that the teleost skull is highly modular, and that morphological disparity is highest around the supraoccipital crest, the posterior region of the maxilla, and at the proximal and distal regions of the lower jaw. The otic capsule region shows the lowest disparity. These preliminary findings suggest that modularity plays an important role in shaping morphological diversity in this clade. Our findings represent an important first step towards broader investigations of teleost modularity, and a more comprehensive understanding of drivers of vertebrate biodiversity.

P39-6 Knasin, L*; Wuitchik, D; Pilcher, C; Vize, PD; Davies, SW; Boston University, Boston, MA, Boston University Boston, MA, Boston University, Boston, MA and St. Lawrence University, Canton, NY, University of Calgary, Calgary, AB, Canada; *lknasin@bu.edu*

The transcriptional response of coral-associated algal symbionts is modulated by natural environmental rhythms

Organismal behavior is influenced by the surrounding environment, an extent of which is modulated by endogenous biological clocks. These timekeeping systems maintain synchrony between internal and external environments, allowing organisms to anticipate and acclimate to future conditions. Broadcast spawning corals rely on changes in seasonal temperature, lunar phase and time of day to synchronize spawning. Responses to environmental rhythms in coral are well studied, but rhythms in their symbiotic algae are not. We investigate gene expression profiles of *Cladocopium goreaui*, the algal symbiont hosted by the coral *Acropora millepora*, across temperatures, lunar phases and times of day to understand how these rhythms interact to influence algae *in-hospite*. RNA from the holobiont was sampled over 24-hr periods across a full lunar cycle at two seasonal temperatures. Symbiont gene expression was

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quantified and networks of co-expressed genes were correlated with environmental rhythms and temperature treatments. Preliminary results show that temperature, lunar phase, specifically the full moon phase, and coral host genotype were more influential in modulating gene expression than time, though analyses are ongoing. A previous study investigating the influence of these three rhythms on the *A. millepora* hosts showed specific genes and core processes were differentially impacted by diurnal-temperature, lunar-temperature and diurnal-lunar interactions. Together, this research can determine the extent coral hosts and their algal symbionts co-regulate one another's biological timekeeping on the genomic level.

P7-5 Knaub, J*; Heerdegen, I; Ruddy, B; Ingle, D; Porter, ME; Florida Atlantic University, Boca Raton, FL, Texas A&M University Galveston, Galveston, TX; *jknaub2020@fau.edu*

Mineral architecture in cartilaginous shark vertebrae

Cartilaginous shark vertebrae have a calcified double cone structure, a morphology that has been shown to impact mechanical properties. Adorning the double cone are mineral structures that vary among species. We aim to quantify mineral architecture of vertebrae from 18 species in three orders of shark (Lamniformes, Carcharhiniformes, and Squatiniformes). Previous literature has shown that posterior vertebrae are stiffer and tougher than anterior vertebrae. We hypothesize posterior vertebrae will have 1) greater quantity of lamellae and nodes (in applicable species), 2) smaller intermedialia angles, 3) larger centrum surface volume, and 4) higher mineral density than anterior vertebrae. Anterior and posterior vertebrae were dissected and scanned using a Bruker SkyScan 1173 μCT scanner. We measured the following morphological variables for each centrum: lamellae number, nodes along the lamellae, intermedialia angles, surface volume, and mineral density of the whole structure and a region of interest surrounding the remnant notochord. Preliminary data from Lamniform sharks show that posterior vertebrae mineral structure is composed of more lamellae and nodes when compared to anterior regions. For all species, mineral density was higher in the posterior region and we predict lower mineral values surrounding the remnant notochord. We hypothesize that the increased mineral architecture and higher mineral density found in the posterior regions contributes to

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stiffness and toughness of the cartilage, and the posterior vertebral column can contribute to more thrust production during swimming.

P23-12 Koenigsmark, A L*; Leinbach, S E; Bely, A E; University of Maryland, College Park; *alkoenigsmark@gmail.com*

Injury from sediment mobility and recovery in two species of stream annelids

Benthic organisms that inhabit stream sediments live in an inherently unstable physical environment, making them susceptible to injury from sediment movements, especially during periods of high flow. Stream flooding is common and is increasing in severity and frequency due to climate change, exacerbating the injury risk to infaunal organisms. Annelids are abundant in stream sediments and their soft, elongated bodies should make them particularly susceptible to injury from shearing and crushing forces of moving sediments. However, such injuries have not previously been studied. We performed laboratory experiments to investigate how sediment size and sediment movement speeds affect injury in two common freshwater annelid species, the tiny naidid *Pristina leidyi* and the large lumbriculid *Lumbriculus variegatus*. We simulated natural sediment mobility by swirling annelids with natural substrates of five size classes at five speeds, and also assessed the recovery of *P. leidyi* following a range of damage severity. Our results indicate that sediment mobility can cause substantial injury to both small and large bodied annelids. The small-bodied *P. leidy* experienced the greatest damage with small to intermediate sediment sizes (fine and medium gravel), while the large-bodied *L. variegatus* experienced the greatest damage with intermediate to large sediment sizes (medium and large gravel). Both species experienced greater injury with increased sediment movement speeds. *Pristina leidyi* exhibited a high capacity to recover from sediment mobility damage, with recovery time and death increasing with injury severity. Our findings suggest that injury from sediment mobility may be ecologically important in soft-bodied stream infauna.

P27-8 Koller, KL*; Kernbach, ME; Martin, LB; University of South

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Seasonality of West Nile virus competence in a widespread reservoir

Identifying the forces driving seasonal rhythms in zoonotic disease risk are necessary to effectively target mitigation efforts, though drivers that persist across distinct environments remain to be described. As the capacity for a host to transmit a pathogen (i.e. competence) is predominantly governed by the immune system (e.g., the duration and magnitude of infectiousness), broad trends in reservoir immune defenses ought to be a central driver of disease seasonality, though this assumption has yet to be examined. To investigate the magnitude of seasonal variation in reservoir immune defenses and the forces driving these rhythms, I performed a series of West Nile virus (WNV) infections in a ubiquitous reservoir. House sparrows (*Passer domesticus*) were captured in the Tampa Bay area and experimentally exposed to WNV across key life history stages. Over the course of infection, I quantified viremia and expression of key modulators of the inflammatory immune response, IFNγ and TNFα. As host immune defenses are modulated through dynamic energy allocation, I hypothesize that competence will be intimately linked to host physiological state, where those infected during times of great energetic demand, (e.g., reproduction and molt) maintain infectiousness for an extended length of time. Furthermore, I predict that life history tradeoffs manifest through reduced expression of the chosen biomarkers of WNV resistance. If these hypotheses are supported, the results from this study will demonstrate seasonal rhythmicity of functional immune defenses in a key disease reservoir and a potentially pervasive driver of zoonotic disease seasonality.

P26-3 Krishnan, AG*; Meyers, D; Long, H; Foltz, S; Reed College, Portland, OR, Radford University, Radford, VA; *anagkrish@reed.edu*

Effects of urban land use on bird vocalizations

Animals that use vocalization as a primary means of communication are impacted by urbanization. These impacts are caused by higher levels of low-frequency ambient noise, which can mask vocalizations, and the layout, structure, and material of buildings, which can influence the way sound travels and is absorbed. The majority of current literature focuses on

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urbanization as a spectrum from rural to urban, and this approach has led to significant findings, notably correlating increased background noise with higher vocalization frequency. However, potential variation within urban soundscapes due to differences in building type, size, and density, as well as in vegetation structure, and resulting impacts on birdsong, are less understood. We conducted a preliminary investigation of how variation in physical and acoustic properties within urban environments may shape bird vocalizations, recording data in two separate urban locations, one on each coast of the U.S. We sampled across four distinct urban environments (suburbs, city parks, college campuses, and downtown business districts) on each coast. Due to the exploratory nature of this project, we sampled all bird vocalizations within a two minute period rather than focusing on a specific species. Songs, calls, and syllable types were manually extracted from the recordings with RavenPro, and a clustering algorithm was developed to group similar syllable types. While data analysis is still ongoing, preliminary analyses support the results of previous studies, with higher frequency vocalizations in noisier locations. This approach to studying urbanization will hopefully allow a deeper understanding of how environmental variation impacts animal communication and ways that species such as songbirds can respond to noisy urban environments.

P41-2 La Barbera, V*; Tassa, Y; Richards, C; Daley, M; Hutchinson, J; Royal Veterinary College, DeepMind, University of California Irvine; *vlabarbera@rvc.ac.uk*

Reinforcement learning based simulation of ostrich locomotion using a whole-body model

To achieve agile and efficient locomotion, animals must integrate neural control with the physical and physiological properties of the musculoskeletal system, subject to the dynamic constraints of the environment. Ostriches are the fastest bird on land, yet achieve this impressive performance with slender lower limbs and only one major toe. Prior research has studied hindlimb biomechanics in detail but the question remains: how are head/neck and wing motions are integrated with these in complex three-dimensional and unsteady behaviours? Furthermore, some robots resemble ostriches' morphology; for example, the robot Cassie

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produced by Agility Robotics. Here we build a complete musculoskeletal model of an ostrich and use it to analyse locomotor dynamics. The model has been assembled in the MuJoCo physics engine, which provides fast computations for physics simulations. In recent years there have been rapid advances in solving complex dynamical simulations using Reinforcement Learning, even involving muscle simulations in the NeurIPS challenges. Using this kind of simulation, another question arises: what is the relationship between musculoskeletal morphology and the learning process? This study provides a complete open source model of the major components of a whole ostrich's musculoskeletal system. We present our preliminary results from control simulations based on Reinforcement Learning (e.g. normal walking/running; obstacle course maneuvering) which have direct applications in robotics and comparative neuromechanics.

P19-9 Lapsansky, AB*; Szabo, I; Tobalske, BW; University of Montana, University of British Columbia; *anthony.lapsansky@umontana.edu*

Do multifunctional locomotor demands constrain the evolution of the avian wing?

We typically think of morphological structures or traits as evolved for a single function, but the natural world is rarely that simple. More often, the parts of an organism contribute to the performance of multiple behaviors across a range of contexts. How this multifunctionality affects the evolution of a trait is an open question in biology. On one hand, a greater number of functions might constrain evolution due to an increased number of trade-offs - i.e. if each function selects for different trait optima, few phenotypic states can perform all functions. Alternatively, a greater number of functions may facilitate diversification by adding complexity to the adaptive landscape of a trait. To effectively test between these two hypotheses requires both a suitable study system and a dataset of considerable taxonomic breadth and depth. Therefore, we used geometric morphometrics to characterize the wings of 2,332 individual birds from 959 species, dwarfing previous studies of avian wing shape. We then tested whether the rate of evolution on the avian wing is determined by the number of fluids in which that wing is used for locomotion.

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Importantly, five lineages of birds use their wings for locomotion in both air and water, while another five lineages of equally volant birds rely on their feet for aquatic locomotion. Thus, this system offers an exciting opportunity to explore how multifunctionality influences the evolutionary process, while controlling for ecology. After accounting for variation due to wing size, we find strong evidence that multifunctionality constrains the rate of wing shape evolution. In the coming months, we will further explore this dataset using multivariate statistical methods to test whether intraspecific variation and evolutionary mode also vary predictably with the number of wing functions.

P9-8 Lau, ES*; Varney, RM; Oakley, TH; University of California, Santa Barbara, The University of Alabama; *emily.lau@lifesci.ucsb.edu*

A tale of four toadfishes: Using a comparative genomics approach to investigate phenotypic evolution in the Batrachoididae

Evolution produces new traits by tinkering with existing genes or through the emergence of de novo genes. Comparative genomics data can be used to explore the interplay between gene recruitment and de novo gene birth during the evolution of novel traits. We focus our studies on the Batrachoididae, commonly known as toadfishes, an diverse family of ray-finned fishes with an arsenal of derived traits such as venom, bioluminescence, and acoustic signaling. Although acoustic signaling is shared across the family, not all toadfishes are venomous or bioluminescent. Currently, there are representative genomes for three out of the four Batrachoididae subfamilies. To complete the genomic sampling across all subfamilies, we sequenced the genome of a bioluminescent toadfish, *Porichthys myriaster*, using Illumina and Oxford Nanopore technologies. We produced a hybrid de novo assembly consisting of 10,949 scaffolds containing 87% core Actinopterygii genes and 29,929 proteins. With this assembly in hand, we aimed to (1) investigate the evolution of natterins, a class of proteins found in toadfish venom, and (2) identify novel or duplicated gene families unique to luminous toadfishes. We identified several natterin homologs and candidate protein homologs for a novel crystallin previously reported in the lens of *Porichthys*'s light organs. Our crystallin candidates are functionally uncharacterized

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and similar proteins are found only in other fishes, fungi, and bacteria. Comparative analyses across toadfish genomes are underway, and we anticipate that our approach will identify conserved and novel genomic features useful for understanding the diversity of genetic mechanisms associated with phenotypic evolution.

P33-7 Laurence-Chasen, JD*; Manafzadeh, AR; Hatsopoulos, NG; Ross, CF; Arce-McShane, FI; University of Chicago, Brown University; *jdlc700@gmail.com*

XROMM Tools for DeepLabCut: Bringing deep learning to XROMM marker tracking

We present XROMM_DLCTools, an open-source workflow that integrates XMALab and DeepLabCut to dramatically increase XROMM (X-ray Reconstruction of Moving Morphology) marker tracking speed. The process resembles typical deep learning pipelines; the user tracks a subset of frames in XMALab, which are used to train a deep neural network with DeepLabCut. The network then predicts 2D marker locations, in both cameras, for novel frames. The predictions can be evaluated and corrected in XMALab, where final triangulation and rigid body reconstruction is performed. The workflow shows special promise for cyclic behaviors (e.g. chewing or treadmill locomotion) where range of motion is constrained and relatively few training frames are needed to capture the majority of the variation in the whole dataset. Our hope is that this new workflow will enable large-scale, multi-taxon studies that were previously precluded by the XROMM marker tracking bottleneck. We provide full instructions and code at github.com/jdlaurence/XROMM_DLCTools.

P13-8 Lee, Y*; Just, J; Young, M; McMahon, T; Gonzalez, J; O'Brien, DM; Angelini, DR; Colby College, Harvard University; *yjlee21@colby.edu*

Mouthpart scaling relationships and foraging behavior in bumblebees

Bumblebees (Hymenoptera: Apidae: Bombus) show an incredible degree of size variation within and between species. Individuals from the same hive may vary up to 10-fold in mass. This variation allows individuals to specialize in foraging on different flowers suited

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to their morphology. However, as different species have different foraging behaviors, their variation and scaling of body sizes and mouthparts may have been constrained in different ways to optimize nectar collection as they coevolved with flowering plants. Here, we examined the scaling relationships between body size and mouthpart structures, and the variation in mouthpart shape between species to determine whether foraging behavior can be differentiated and inferred using these patterns. We sampled 7 bumblebee species throughout Maine, a region of high bumblebee species diversity, biogeographic variation, and diverse land-use histories. Variation in the size and shape of mouthparts was analyzed for each species using multivariate morphometric analyses to identify species and caste differences. Our results indicate that generalists, such as *B.bimaculatus*, *B.vagans*, and *B.impatiens*, display wider variation in the shape of mouthpart structures and isometric scaling relationships between tongue and body size, while niche species, such as *B.ternarius* and *B.terricola*, display narrow variation and canalized slopes of zero. Two species, *B.borealis* and *B.fervidus*, were strikingly different in mouthpart size and shape compared to others, perhaps due to their early evolutionary divergence from the rest of the genus. Overall, these patterns support the hypothesis that different bumblebee species have different pollination strategies: generalists have a variety of mouthparts suited for different flower species, while specialists focus on certain flowers with a consistent morphology.

P41-11 Lee, SD*; Wang, LK; Stuart, H; Full, RJ; University of California, Berkeley; *sebastiandavidlee@berkeley.edu*

Landing branch reaction forces in jumping fox squirrels

Small, tree-dwelling animals rely on acrobatic maneuvers, such as jumping, to negotiate complex, three-dimensional arboreal terrains. These quick maneuvers can involve high velocities and accelerations which result in high dynamic forces. To understand these maneuvers, we measured the forces exerted by free-ranging fox squirrels as they landed on branch-like rods. We used high-speed cameras and a 6-axis force/torque sensor to investigate the landing mechanics of squirrels jumping across two parallel rods perpendicular to the path of motion. The 0.75-inch landing rod was instrumented with the load cell and placed 50 cm away from the take-off rod. Data for 800

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g squirrels showed a peak average, total landing force of 17.3 N or 220% body weight. The peak occurred after the front limbs touched down, but before the hind limbs made contact with the rod. Total peak force occurred 40 ms after the forelimbs first contacted the rod. The 50% rise time prior to peak force was 12 ms and the decay time to 50% after the peak was 45 ms. Hind feet touchdown occurred 150 ms after front foot touchdown. Peak horizontal, deceleration reaction forces in the direction of forward motion equaled 136% of body weight. Peak vertical landing forces were 173% of body weight. Time to execute landing, when horizontal force equaled zero, was ~300 ms. Our experimental test bed will be used to measure take-off, landing, and grip forces that characterize energy absorption and generation, anchoring, and adjustments to surface properties. We plan to vary rod diameter and surface properties, gap distance, and rod compliance to test decisions about landing strategies that integrate responses from foot biomechanics to path decisions.

P5-3 Lincoln, JM*; Bukovich, IMG; Rucker, HR; Baedke, PE; Bartoszek, I; Parker, MR; James Madison University, Harrisonburg, VA, Conservancy of Southwest Florida, Naples, FL; *lincoljm@dukes.jmu.edu*

Skin lipids in Burmese pythons: comparison of data analysis approaches to multidimensional data

Chemical signals in vertebrates are often complex blends of molecules, many of which have independent and/or synergistic effects on receiver behavior. While isolation of these chemical mixtures is relatively straightforward, meaningful, targeted analysis of the blends can be challenging. Our lab studies the chemical composition of skin lipids that serve as communication signals in many reptile species. We treat these lipid blends as multidimensional datasets to which Bayesian statistical techniques can be applied. Here, we present an analytical framework for dealing with multidimensional chemical data from Burmese pythons (*Python bivittatus*). In collaboration with scientists at the Conservancy of Southwest Florida, we isolated a series of skin lipid fractions from reproductive pythons caught in mating aggregations during the breeding season across two years (n=17 males; n=19 females). These pythons are a major invasive predator of concern in Florida, and discovering the chemicals comprising

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their mating signals is a major target for biological control. In R, we used randomForest to predict the response variable ″sex” based on gas chromatograph (GC) retention times to identify informative chemical peaks. In parallel, multiple response permutation procedure (mrpp) was used to conduct a global analysis of sex differences per fraction followed by nonmetric multidimensional scaling to visualize differences. Lipid profiles varied significantly between sexes across the different fractions, with randomForest accurately predicting sex in ~80% of the fractions. By using importance plots, we have identified key GC peaks for further testing.

P11-8 Lindsey, AG*; Beatty, AE; Schwartz, TS; Auburn University; *agl0032@auburn.edu*

Effects of Insulin-like Growth Factors (IGF1 and IGF2) on brown anole lizard tail regeneration

Some reptiles, such as the brown anole lizard (*Anolis sagrei*), possess the ability to autotomize, via breakpoints in the vertebrae, and regenerate their tails. While tail regeneration is common among lizards, the molecular mechanisms of tail regeneration remain understudied. One molecular network involved in the regulation of regeneration is the insulin and insulin-like signaling (IIS) network, which have previously been shown to regulate physiological processes such as reproduction, aging, growth, and wound healing across clades. Although the IIS network has been shown through transcriptomic analyses to be associated with wound healing and regeneration in reptiles, the potential regulation of regeneration by the IIS network remains ill-defined. To explore this relationship, we focus on two hormone regulators of the IIS network: IGF1 and IGF2. To test whether increasing levels of IGF1 or IGF2 will increase the rate of tail regeneration, adult female brown anoles (N=80) were randomized into four groups: *Ad lib* diet (8 crickets weekly), limited diet (4 crickets weekly), limited diet and IGF1 injection, and limited diet and IGF2 injection. Following three weeks of diet acclimation, tail autotomy was induced for all lizards and IGF injections were administered subcutaneously. Regenerated tail length, weight, and reproductive output were tracked weekly for eight weeks. We predict that if IGF1 or IGF2 play a role in the regulation of tail regeneration, then

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IGF injections will increase the rate of tail regeneration in the IGF1 and IGF2 groups. Final results and the prospect of the IIS network as a molecular influence of regeneration will be discussed.

P11-5 Lissner, J N*; Press, L; Meier, P T; Muhlenberg College; *JNLissner@muhlenberg.edu*

Anatomical correlates of climbing behavior in Peromyscus

The diversity of species (56) of North American mice within the genus *Peromyscus* reflects the wide range of habitats they occupy and corresponding variation in behavior and morphology. We studied differences in climbing behavior and anatomy among three populations of mice (*P. maniculatus gracilis, P. m. bairdii*, and *P. leucopus noveboracensis*) that can be found in the same general geographic area, but tend to use different habitats that vary in tree cover. Laboratory trials revealed statistically significant differences among populations in tendency and ability to climb on both horizontal and vertical rods. Differences in tail length were found among the populations, but tail length by itself did not predict differences in climbing behavior. Other morphological differences among the populations appear to be at least equally important in explaining differences in climbing behavior.

P1-7 Lowe, CL*; Hunt, KE; Rogers, MC; Robbins, J; Neilson, J; Gabriele, C; Teerlink, S; Seton, R; Buck, CL; Northern Arizona University, Flagstaff, AZ, George Mason University and Smithsonian-Mason School of Conservation, Front Royal, VI , Alaska Fisheries Science Center Auke Bay Laboratories, NOAA Fisheries, Juneau, AK , Center for Coastal Studies, Provincetown, MA , Glacier Bay National Park, Gustavus, AK , Protected Resources Division, National Oceanographic and Atmospheric Administration, Juneau, AK , College of the Atlantic, Bar Harbor, ME; *carley.lowe@gmail.com*

Multi-year progesterone profiles during pregnancy in baleen of humpback whales (Megaptera novaeangliae)

Understanding calving rates of wild whale populations is critically important for conservation. Reproduction of humpback whales is difficult to monitor and basic physiological information such as pregnancy rates and calving intervals remain unknown. We

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hypothesized that pregnant whales have sustained elevations in baleen progesterone that temporally correlate with gestation. To test this hypothesis, baleen progesterone profiles from two adult female North Pacific humpbacks, both with extensive sightings records and documented pregnancies, were compared to those of a nulliparous female and a juvenile male. Baleen specimens were collected at necropsy and subsampled every 2 cm. Progesterone was quantified using enzyme immunoassays with the date of growth of each sampling location confirmed via stable isotope analysis. Progesterone profiles from both pregnant whales showed sustained high progesterone content in areas corresponding to known pregnancies, inferred from calf sightings or post-mortem data. The younger female had higher progesterone during pregnancy than the older female but levels during non-pregnancy were similar. The nulliparous female and the male had low progesterone throughout their baleen plates. Baleen hormone analysis can determine how progesterone changes throughout gestation and has potential for estimation of reproductive history and calving intervals.

P10-9 Lungstrom, LL*; Nash, CM; Westneat, MW; University of Chicago, Chicago, IL; *lllungstrom@uchicago.edu*

Geometric morphometrics of the goatfishes (Mullidae) to explore ecomorphological patterns

The morphology of organisms is heavily influenced by their interactions with their environment. Thus, understanding the evolution of morphological structures and adaptations of an organism is critical when examining the environment in which they live. The goatfishes (Mullidae) are an ideal family to study this integrative relationship because of their diverse ecology and unique morphological structures like the barbel. Previous research has shown that there is variation in foraging behaviors and substrate type preferences among the 95 species in Mullidae. Our research is focused on 1) quantifying the amount of variation in morphology among species of goatfish 2) investigating evolutionary trends of morphology and 3) analyzing the relationship among morphology and ecology. Using a robust photo database of approximately 300 images spanning the majority of species in Mullidae, we determined and placed 46 landmarks on each image that capture important morphological structures of goatfish. To analyze

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the variation of these morphological structures among species, we performed a geometric morphometric analysis using a principal component analysis (PCA). Additionally, we compiled a comprehensive trait database that contains information such as preferred substrate type and diet. Preliminary results suggest that genera tend to cluster morphologically and that head size and body shape are important morphological distinctions. In addition, various ecological parameters, such as substrate preference and diet, seem to correlate with morphology. This understanding of goatfish morphology and its correlation with their ecology is important considering environmental changes and their affect on the persistence and diversity of species.

P35-9 Lusk, EP*; Casto, JM; Illinois State University; *elusk@ilstu.edu*

Creepy Crawly Compensation: Examining the costs of ectoparasite-induced compensatory growth in late-stage nestlings

When normal growth rates are suppressed, organisms may undergo a rapid period of increased growth in order to match the physical requirements of a developmental benchmark. This compensatory growth, however, is not without its costs, which can have varying consequences. In nestlings, a major benchmark is that of fledging, which requires advanced physical maturation. In previous studies, compensatory growth and some of its associated costs have been shown in pre-fledging nestlings but fledging-aged nestlings and the costs they may have sustained needs further study. Here we examine the costs of compensatory growth in late-stage European starling (*Sturnus vulgaris*) nestlings under the developmental stress of ectoparasitic infestation. Nests were subjected to either the addition of Northern fowl mites (*Ornithonyssus sylviarum*) or ectoparasite reduction through use of the miticide Permethrin. We followed nestlings throughout development, and at 10 and 20 days of age, assessed structural growth and collected blood to determine hematological measures and corticosterone titers. On day 20, the day prior to when starlings typically leave their natal nest, their brains were harvested. Starlings under ectoparasitic conditions had significantly smaller wingspans, tarsus lengths, and bodyweights on day 10, but on day 20, structural growth was indistinguishable from nestlings in miticide treated nests - suggesting compensatory

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growth. While we have yet to assess hemoglobin and corticosterone levels, analyses show that brain weight and hematocrit were significantly lower in nests with ectoparasites on day 20, perhaps indicating the protection of necessary physical traits for fledging through compensatory growth at the cost of these less apparent attributes.

P5-5 Ly, SH*; Collin, R; Northeastern University, Smithsonian Tropical Research Institute; *ly.so@northeastern.edu*

Temperature changes during oogenesis impact the offspring size of a tropical slipper limpet

It is well understood that offspring size in ectotherms is highly responsive to changes in temperature, but the processes that underlie this response are not as well studied. We investigated when temperature changes induce a shift in the offspring size of the common tropical slipper limpet, *Crepidula cf. marginalis* as well as the duration of time it takes for offspring to reflect the temperature experienced by their mother. After collecting the juveniles at Playa Venado, Panama, the animals were raised in the laboratory at either 24° C or 28° C, temperatures normally experienced in their natural habitat, and moved reciprocally between the temperatures. In the first experiment, we moved animals to the other temperature after oviposition to establish whether differences in offspring size is attributed to either the temperature experienced during oogenesis or embryogenesis. In the second experiment, we moved animals after the hatching of their first brood and measured the following three broods to establish the length of time that the legacy of the first temperature remains. We determined the thermal experience of the mother during oogenesis significantly impacts offspring size and that offspring size is affected for at least two broods after a temperature change. These results indicate offspring size is determined by the temperature experienced prior to oviposition and that this thermal legacy lingers for no more than two brooding cycles. It is unknown whether this rapid thermal acclimation is an adaptive feature or a response to an oogenetic physiological limitation. Further research into the ways in which temperature affects offspring size will provide a deeper understanding into the potential for organisms and

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ecosystems to respond to temperature changes induced by climate change.

P14-6 Lynn, SE*; Benowitz-Fredericks, ZM; College of Wooster, Bucknell University; *zmbf001@bucknell.edu*

"Hormones & Society"in Endocrinology: Bringing social justice issues into a STEM classroom

Many college science courses do not engage with the interface of science and social justice. Common reasons include reluctance to reduce other course content, and discomfort with navigating conversations about bias and privilege in the classroom. We evaluated student perceptions of the benefit and consequences of explicitly incorporating social justice themes in an upper level endocrinology course. We implemented "Hormones & Society" modules in 2 such courses at liberal arts institutions. Topics were aligned with traditional endocrinology content and included: unequal access to diabetes treatment (pancreatic function), endocrine disruption and environmental racism (thyroid function), sterilization and birth control as eugenics tools (HPG axis and reproductive physiology), gender assignments for intersex newborns (sex differentiation), health impacts of shift work (biological rhythms), and early life stress and health disparities (HPA axis). We incorporated up to six 1-2 hour modules per semester. In our first session, students defined social justice, shared concerns, and laid ground rules for engaging in discussions. Homework included reading primary literature, reports, and opinion pieces, and answering reading questions. In class, groups of 3-4 students engaged with discussion prompts, followed by class-wide discussion. At the end of each semester, students were asked to complete an anonymous (IRB-approved) survey about the class. 89% of respondents felt that this approach was a valuable use of class time and 94% indicated that they would like to see more biology courses directly connect course content to social justice issues. We conclude that upper level endocrinology courses are amenable to the intentional inclusion of issues of social justice, and that many students are eager for this.

P14-7 Lyons, AM*; Tribble, CM; Beal, D; Wefferling, K; Wrensford,

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Project Field Equity (Fe): A three-pronged approach to preventing SVSH and maximizing inclusivity in biological fieldwork

Project Field Equity (Fe) is a student organization dedicated to preventing and addressing sexual violence and sexual harassment (SVSH) during biological fieldwork. Fieldwork increases the risk of SVSH due to the frequent isolation of researchers and unique interpersonal dynamics. Often, standard institutional policies are inadequate for these special circumstances. Project Fe developed a framework for SVSH prevention to be implemented at the lab, department, and/or institutional level. Our framework consists of three pillars: education, policies and safety recommendations, and addressing social norms. (1) Educate researchers: working with experts in SVSH prevention and field safety, we provided trainings for faculty, staff, and students specifically addressing SVSH in the field. Future work will expand reach and institutionalize trainings within existing offices and programs. (2) Implement prevention policies: in close collaboration with SVSH prevention and reporting groups, student health resources, and field safety experts, we developed a flexible field code of conduct to promote safer field experiences and clarify expectations in the field. (3) Shift social norms: using the social norms approach for behavioral change, we developed a flyer-based media campaign to shift attitudes regarding acceptable behavior in the field. Here, we discuss this three-pronged framework and provide working examples from our own institution, at the University of California, Berkeley, including examples of flyers from our media campaign. We hope that these resources will serve as actionable tools for SVSH prevention, policy, and education that can be implemented across a number of institutions, stages of scientific training, and field sites.

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P28-10 Mack, JM*; Martinsson, S; Klinth, M; Erséus, C; Bely, AE; University of Maryland, College Park, University of Gothenburg; *joemack@umd.edu*

From mud to meat: Employing phylogenetics and metabarcoding gut-content analyses to test evolutionary hypotheses of trophic transitions in a group of predatory annelids

Trophic shifts are powerful drivers of animal diversification. The transition into carnivory is a profound dietary shift that has evolved numerous times in animals, but underlying mechanisms for this transition are poorly understood. Lineages that have recently adopted predatory lifestyles are thus compelling models for understanding the proximate and ultimate causes behind animal carnivory. Within the phylum Annelida, ancient origins of carnivory have led to highly successful groups like leeches, while recent acquisitions of carnivory have also occurred. *Chaetogaster*, a genus of predatory, asexual freshwater oligochaetes is one widespread example, making it an outstanding model to study the integrative biology of this transition. We present a new molecular phylogeny of the genus, using COI and ITS2 from 264 specimens collected across Europe and North America, plus an 18S metabarcoding gut-content analysis on a subset of specimens. Our phylogeny identifies 16 putative new species, suggesting wide-scale cryptic diversity, and reveals surprising relationships between the known parasitic, predatory, and omnivorous representatives. The gut-content analysis is in progress, with the goal of identifying prey DNA in the guts of worms and mapping dietary transitions onto the tree. Combining our phylogenetic and gut content data, we will test several scenarios of trophic evolution that link the diets of basal, potentially non-predatory *Chaetogasters* to the highly predatory condition of more derived *Chaetogaster* species. This study will illuminate possible transitions that led to other diverse carnivorous lineages, such as leeches, and it will improve our understanding of trophic evolution in animals.

P20-6 Maclaine, KD*; Stebbings, KA; Havird, JC; The University of Texas at Austin; *zwonitz2@utexas.edu*

The powerhouse of the cell has the power to influence mtDNA mutations

Mitochondria contain their own genome, mtDNA (mitochondrial DNA), which codes for products necessary for metabolism and mitochondrial function. Disruption of the mtDNA sequence can lead to a decrease in organismal fitness. To further understand the effects of mtDNA mutations, the PolG mutant mouse was created, which contains a mutated mtDNA proofreading mechanism and accumulates mtDNA mutations, leading to premature aging and death. The aging

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mechanisms and physiology of PolG mice have been well studied, but little has been done to analyze the location, frequency, and diversity of their specific mtDNA point mutations and indels. Previous studies on the PolG mtDNA spectrum have been limited by sample size or have not covered the entire mtDNA genome. This study explores the mtDNA mutation spectrum of the PolG mouse using metrics that are specific to mtDNA. Mutation counts, which quantify mutation diversity, and frequencies, which report mutation abundance, were the lowest in the d-loop, where the mtDNA origin of replication is located. Germline mutations had a lower probability of causing missense or nonsense changes compared with somatic mutations, likely because they screened more effectively by natural selection. Cytosine to thymine mutations are the plurality of mutations in the PolG mouse and appear to primarily contribute to a change in hydrophobicity in protein products. Our results provide insight into the connection between aging and mtDNA mutations as well as how selection acts on mtDNA mutations within an organism.

P21-9 MacLeod, LM*; Racy, JM; Summers, AP; Kolmann, MA; University of Washington, Friday Harbor Labs, University of Washington, Friday Harbor Labs, University of Michigan Museum of Paleontology; *leomac18@uw.edu*

Fin-triguing fish: functional equivalency of jaw morphologies of fin- and scale-feeding piranhas'

Fishes exhibit a wide range of dietary ecologies, feeding on everything from the tube-feet of echinoderms to cultivated strands of algae, and even include some of the few examples of vertebrate ectoparasites. Ectoparasitic fishes feed on the blood, fins, scales, and slime of other fishes and appear particularly abundant in tropical South American freshwaters. Of these, the best-known fin-feeders (pterygophagous) and scale-feeders (lepidophagous) are piranhas (Serrasalmidae). While scales and fins are made from fundamentally homologous materials, the differences in how these materials are arranged on prey suggests that piranhas need different tools or behaviors to obtain either resource. Therefore, consuming only the scales or fins of other fishes (and associated mucus), seems like a specialized niche, so we might expect these fishes to have distinctive morphologies relative to other generalist carnivores. We tested for phenotypic differences among

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ectoparasitic, carnivorous, and omnivorous piranhas by examining cranial morphometrics obtained from microCT scans for 80% of the described piranha species diversity. We also explored whether jaw morphologies among ectoparasitic lineages are phenotypically or functionally convergent, by examining trait evolution across the latest piranha phylogeny. Finally, we affixed cutting blades to a mechanical loading frame and determined how much force is required to remove fin rays from prey. While some ecological specialists like *Catoprion mento*, an obligate lepidophage, were distinct from other piranhas in our analyses, most scale- and fin-feeding piranhas overwhelmingly resembled their carnivorous cousins. Forces required to remove fins fall well within the range of published bites forces for even the smallest piranha species.

P15-4 MacNiven, L*; Hamar, J; Kültz, D; University of California, Davis, Animal Science; *lmrechlin@ucdavis.edu*

Hyperosmolality induces nuclear translocation of osmotic stress transcription factor 1 in Oreochromis mossambicus cells

Euryhaline fish tolerate a wide range of environmental salinity by employing molecular mechanisms for coping with the associated osmotic stress. We have previously shown that osmotic stress transcription factor 1 (OSTF1) is part of these mechanisms. OSTF1 is transiently and rapidly upregulated in gill epithelial cells of tilapia (*Oreochromis mossambicus*) exposed to hyperosmolality. Hyperosmotic induction of OSTF1 in tilapia gills was reproduced in the tilapia OmB cell neuroepithelial cell line. OSTF1 shares the signature sequence of the TSC-22 family suggesting that it is a transcriptional repressor. If, in fact, OSTF1 is a transcription factor, we hypothesize that it will localize to the nucleus during hyperosmotic stress. Using standard cloning procedures, OSTF1 was tagged with enhanced green fluorescent protein (EGFP) at either the C- or N-terminus. Using fluorescent microscopy we show that the fusion proteins are retained in the cytosol under iso-osmotic conditions. To evaluate potential nuclear translocation of OSTF1 during hyperosmotic stress, we subjected OmB cells expressing the OSTF1:EGFP fusion protein to hyperosmotic media and imaged at time intervals from 5 minutes to 4 hours using a Leica Dmi8 microscope with automated scanning stage. At four hours and 650 mOsmol/kg, subcellular localization quantified by LASX image analysis (Leica)

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demonstrated that OSTF1:EGFP was mostly localized to the nucleus. This result supports our hypothesis that OSTF1 is indeed an osmotically inducible transcription factor. Current work evaluates influence of specific OSTF1 domains on nuclear localization. Funded by a NSF grant IOS-1656371.

P27-4 Madelaire, CB*; Zena, LA; Dillon, D; Pereira, D; Hunt, KE; Bícego, KC; Buck, CL; Gomes, FR; Northern Arizona University, São Paulo State University, University of São Paulo; *cmadelaire@yahoo.com.br*

Body temperature is more important than seasonality and steroid levels in determining immunity in the hibernating tegu lizard

Multiple factors can impact the immune function of ectotherms, including hormones levels, seasonality, sex, body condition and body temperature. We investigated the seasonal covariation of steroid levels (testosterone for males, estradiol and progesterone for females, and corticosterone for both sexes), immune parameters (total and differential number of leukocytes, plasmatic bacterial killing ability), body condition index and body temperature in males and females of the tegu lizard (*Salvator merianae*). This species displays pronounced transitions in life history stages along the year: reproductive period, non-reproductive period, and hibernation. We expected immunity to be correlated with body temperature, steroids levels and body condition. We also expected lower immunocompetence during hibernation compared to the other life stages. We observed a positive correlation between differential number of leukocytes and body temperature experienced one week prior sampling. On the other hand, BKA and total number of leukocytes were not influenced by body temperature, indicating that some immune traits are viable under a wide range of temperatures. Against our hypotheses, there were no correlations between hormone levels, body condition and immune traits. Also, immune parameters did not decrease during hibernation. Our data indicates how important is to understand the relationship between body temperature and immune response in ectotherms, especially on a climate change scenario. The lack of correlations between immune variables, hormones levels and body condition emphasize that patterns of variation in immune response in reptiles can depend on

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the species, immune parameters analyzed and other ecological traits.

P25-13 Madelaire, CB*; Zena, LA; Dillon, D; Pereira, D; Hunt, K; Buck, CL; Bicego, KC; Gomes, FR; Northern Arizona University, University of São Paulo, Sao Paulo State University; *cmadelaire@yahoo.com.br*

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P40-8 Maeda, M; Henningsson, P*; Royal Veterinary College, Hawkshead Lane, Hatfield, AL97TA, U.K., Lund University, Faculty of Science, Department of Biology, Sölvegatan 37, 223 62, Lund, Sweden; *per.henningsson@biol.lu.se*

Aerodynamics of manoeuvring flight in pied flycatchers (Ficedula hypoleuca)

In the daily life of any flying animal, manoeuvring is something that is ever present: predators pursuing prey, prey avoiding predator, flying through cluttered environments, and so on. Therefore, how the animals perform their manoeuvers and what it cost for them to do so, is of utmost importance to their biology and ecology. For a flycatcher, a small bird that catches insect prey on the wing, manoeuvrability is central and the birds perform various manoeuvres constantly in their everyday routine flights. Here we present the results from a study of the aerodynamics and kinematics of manoeuvring flight in flycatchers in a wind tunnel. We performed a set of experiments where we used time-resolved stereo particle image velocimetry (PIV) to capture the wake generated by the birds while they were performing lateral manoeuvres. At the same time the birds were recorded with four high-speed cameras to extract body, wing and tail kinematics. To encourage the birds to perform the manoeuvers, we laterally translated a thin carbon fibre sting holding a mealworm at the instant just before the flycatchers approached their prey. This resulted in three different phases captured within each recorded sequence; (i) initiation of the manoeuver, (ii) lateral displacement, and finally (iii) termination of the manoeuver and stabilization. We explain the mechanistic basis of the manoeuvres and discuss the results in the context of flight performance.

P9-9 Mah, JL*; Dunn, CW; Yale University; *jasmine.mah@yale.edu*

A phylogenetic analysis of the tempo and mode of cell type evolution

An enduring evolutionary puzzle is the question of why some animals have high cell diversity (such as humans, who possess at least 500 hundred morphologically distinct types of cells), while others have lower diversity (such as *Trichoplax adhaerens*, which has 6 to 30 morphologically distinct cell types). Here I present a phylogenetic analysis of the tempo and mode of cell type evolution. I have

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constructed cell phylogenies, where the taxa are cells and characters are gene expression. This was achieved by transforming single cell RNAseq abundance data to a gaussian distribution, allowing us to leverage existing models of continuous trait evolution for phylogenetic inference. To study the origin of cellular dynamics, I concentrate my analyses on a key position of the animal tree - the four non-bilaterian clades (Ctenophora, Porifera, Placozoa and Cnidaria) - investigating a species from each. I examine the geometry of these cell phylogenies to determine the overall tempo of cell type evolution in each species, and ask whether diversity in the rate of cell type diversification underlies the variation in cell richness seen across species. I find that while rates of loss are constant and low, the four non-bilaterian species have varying cell diversification rates which, in all species, decline over evolutionary time. By investigating the tempo and mode of cell type evolution, I hope to shed light on the origins of animal diversity.

P25-11 Maloney, ME*; Pomory, CM; University of West Florida, Pensacola; *mem0294@auburn.edu*

Heat stress and energetic components in Cassiopea xamachana

Cassiopea xamachana was collected from the Florida Keys, Florida, USA, and the effect of sub-bleaching heat stress on percent composition of energetic components (protein, carbohydrate, lipid) under differing salinity and light conditions was measured. Jellyfish were subjected to a heat-stress event by elevating temperatures to 33° C over seven days, or no heat-stress control, and were then held for eight weeks under a salinity of 30 g kg^{-1}, 35 g kg^{-1}, or 40 g kg^{-1}, and either a higher or lower light exposure. A small initial sample at the end of the heat-stress event indicated no difference in zooxanthellae count. At the end of eight weeks no difference was found between heat-stress and no heat-stress treatments for zooxanthellae count, or any energetic component; however, a decrease in carbohydrate was associated with lower light exposure, and possibly the highest salinity. The results indicate *Cassiopea xamachana* is resilient/resistant to short-term heat-stress events, even when coupled with varying conditions of salinity and light.

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P33-6 Manafzadeh, AR*; Gatesy, SM; Brown University, Providence, RI; *armita_manafzadeh@brown.edu*

A coordinate-system-independent method for comparing joint rotational mobilities

Since the advent of X-ray Reconstruction of Moving Morphology, studies of joint range of motion (ROM) have become increasingly common in comparative biomechanics. These 3-D ROM studies have typically plotted poses measured from a joint coordinate system in "Euler space." The axes of Euler space are angles measured in each of the joint's three rotational degrees of freedom (for example, flexion-extension, abduction-abduction, and long-axis rotation). Researchers then virtually shrinkwrap the pose cloud with an alpha shape and compute its volume to measure rotational mobility. However, pairs of poses that are equally different from one another in orientation are not always plotted equally far apart in Euler space -- rather, they are plotted farther and farther apart as the magnitude of the second rotation approaches +/- 90 degrees. This distortion causes a single joint's mobility to change when measured based on different joint coordinate systems and precludes fair comparisons among joints. Here we present our work on two alternative spaces, both inspired by a 16th century map projection: cosine-corrected and sine-corrected Euler spaces. Plotting 3-D joint poses in these spaces allows coordinate-system-independent comparisons of joint rotational mobilities. When tested with data from a Helmeted Guineafowl (*Numida meleagris*) hip joint, cosine-corrected Euler space demonstrated a ten-fold reduction in variation among mobilities measured from three different joint coordinate systems. This new quantitative framework enables previously intractable, comparative studies of articular function, and can also be applied to other research questions involving 3-D orientation.

P1-3 Martinez, V*; Grace, JK; Texas A&M University; *vm_983277@tamu.edu*

Avian stress hormones along an elevation gradient in west Texas

Mountains support high levels of biodiversity due to their complex climatic gradients. Increases in elevation are accompanied by

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changes in atmospheric pressure, temperature, and solar radiation, which lead to differences in predation pressure, food availability, and energetic requirements for species. These environmental differences may prompt hormonal changes along elevation gradients, although few studies have investigated this relationship. Glucocorticoids are steroid hormones that influence metabolism, the immune system, and are used to maintain homeostasis. This study investigates avian glucocorticoid levels during the breeding season along an elevation gradient in west Texas, an area predicted to be a hotspot for climate change. We present preliminary results from two field seasons and discuss them within the context of the ongoing project. Understanding differences in the passerine bird stress response as elevation increases may indicate future probability of survival as climate change forces elevation range shifts in these species.

P35-2 McAlister, SM*; Hurley, LM; Indiana University ; *siemcali@iu.edu*

Male mice behavioral response to female squeak intensity

In opposite-sex interactions, male mice produce high-frequency ultrasonic vocalizations (USVs). In contrast, females produce broadband vocalizations (BBVs), commonly referred to as squeaks, which are accompanied by physical rejection of the male. While many studies have explored various aspects of USVs, little is known about what components of female BBVs males respond to the most. Our experimental design separated males from females with a perforated barrier, allowing us to measure male USV production in response to playbacks at varying intensities (low, intermediate, or high) without the confound of physical rejection. Our 15-minute playback included two 5-minute intervals of silence surrounding a cluster of female BBVs, which followed a natural time sequence but were replaced with a repeated exemplar squeak. We hypothesized that higher intensity calls would increase male USV suppression, possibly indicating that increased female vocal efforts aid in rejection signaling or help relay female urgency. Using a repeated measures design, we found that the male response was variable, with most males experiencing a considerable (20-80%) reduction in USV production in the first minute of the playback. The loudest (i.e., most intense) stimulus caused the most persistent suppression of

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USVs. We also found that stimulus presentation order and dominance status did not influence the amount of USV suppression. Overall, these findings suggest that males respond to more intense BBVs, possibly indicating that female BBVs aid in rejection signaling or signal increased female urgency.

P29-9 McCabe, TC*; Gillen, CM; Kenyon College, Gambier, OH; *mccabe2@kenyon.edu*

Sequence analysis of cation-chloride cotransporters in mosquitoes

Sodium-dependent cation chloride cotransporters (NaCCC) participate in transepithelial salt movement. AeNKCC1 is the *Aedes aegypti* ortholog to Ncc69, a *Drosophila melanogaster* electroneutral Na-K-2Cl cotransporter. In contrast, aeCCC2 and aeCCC3 may be electrogenic and potassium-independent, despite their sequence similarity with aeNKCC1. We hypothesize that these functional differences reflect differences in primary amino acid sequence of the transmembrane domains (TMD). We developed R code to explore amino acid conservation across TMDs of the NaCCCs from 10 mosquito species. Within each paralog, the TMDs are more than 90% conserved across species (NKCC1: 95% +/- 6, CCC2: 91% +/-9, CCC3: 92% +/- 5.7, n = 10). Across paralogs, the TMDs are less well conserved with average conservation ranging between 62 and 95%. Conservation varies by TMD. The conservation of TMDs 1, 6, and 10 is between 83% and 95%; the conservation of TMDs 2, 3, 4, and 8 is between 70% and 77% and the conservation of TMDs 5, 7, and 9 is between 61% and 70%. Across all 10 TMDs, 66% of residues are fully conserved both within NKCC1 and within CCC2 paralogs; of those residues, 35% differ between the paralogs. Similarly, 64% of residues are fully conserved both within NKCC1 and within CCC3; 32% differ between paralogs. Although 57% of residues are fully conserved within both CCC2 and CCC3, only 6% of those residues differ between the paralogs. Across all ten TMDs, less than 0.5% of residues were fully conserved within each paralog but had a different amino acid in each paralog. Thus, conservation between CCC2 and CCC3 is higher than conservation between either paralog and NKCC1. The fully conserved residues that differ between the NKCC1 and CCC2/CCC3 paralogs are good candidates to explore for roles in the functional differences between the paralogs.

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P37-1 McCabe, EA*; Kwun, C; Harmon, IP; Cantelon, CL; Solomon-Lane, TK; Scripps College, Claremont McKenna College, Pitzer, Scripps, Claremont McKenna Colleges; *tsolomonlane@kecksci.claremont.edu*

Is a social group the sum of its parts? The relationship between group structure and individual phenotype in a highly social fish

There is a complex relationship between the social and spatial dynamics of a group and the behavioral phenotype of group members. We studied juvenile *Astatotilapia burtoni*, a highly social African cichlid fish, to test how individual behavior and group structure are related. We formed groups of five fish and recorded activity for 3 weeks. We also manipulated the presence/size of a clay territory structure to influence how individuals behave or situate in the tank. Tanks had a large, small, or no clay structure for one week, and presentation order was balanced across tanks. The position of each fish in the tank was analyzed on the 8th day of each condition. Afterwards, individual behavior was tested in four sequential assays: open field exploration, social cue investigation, dominance behavior, and subordinate behavior. We found significant variation in fish location in the tank, as well as and distance from each other. The presence/size of the clay structures also significantly affected fish position. This demonstrates that individuals use space differently, depending on the social group and physical environment. Next, we tested the hypothesis that group differences can be attributed to the behavioral phenotypes of group members. For example, we test whether aggressive individuals (in the dominance behavior test) situate farther from other fish and disproportionately influence group spatial distribution. Ultimately, by focusing on variation across individuals, time, and context, we can better understand the dynamic interplay between individual behavior and social group structure, as well as the evolution and regulation of sociality.

P1-4 McClelland, SJ*; Woodley, SK; Moravian College, Duquesne University; *mcclellands@moravian.edu*

Validation of waterborne corticosterone measurement in juvenile leopard frog: Dos and don'ts

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The measurement of waterborne corticosterone (CORT) concentrations in amphibians is becoming increasingly common. It is promoted as a minimally invasive method of accurately assessing physiological stress with conservation and management implications. It is important that waterborne CORT be explored thoroughly to validate its use as a measure of health, yet many studies complete only a partial validation. In addition, there has been some question as to whether this approach is applicable in terrestrial amphibians. We conducted a multi-pronged validation of waterborne CORT in juvenile Northern Leopard Frogs, which is a common amphibian model in both the laboratory and wild. Our approach included assay validation, injecting animals with adrenocorticotropic hormone (ACTH), using a handling challenge, and analyzing different developmental stages. This presentation will focus on results in juvenile Northern Leopard Frogs, identifying when waterborne CORT levels accurately reflect plasma CORT levels. This study is a valuable contribution to the field as it helps researchers to confidently interpret the meaning of waterborne CORT in a terrestrial-phase amphibian.

P3-4 McCubbin, S*; de Castro , NS; Cooper, RL; Universisty of Kentucky Lexington, KY, Lafayette Senior High School, Lexington, KY; *Shelby.McCubbin@uky.edu*

The effects of levetiracetam on glutamatergic synaptic transmission: crayfish and Drosophila NMJs

Epilepsy is a neurological disorder characterized by recurring, unpredictable seizures. Its disease burden is high, seeing as it ranks fourth in the world's neurological disorders burden following: tension-type headaches, migraines, and Alzheimer's disease. The commonly used antiepileptic drug levetiracetam (Keppra) reducing epileptic seizures; however, the exact mechanism is not known. Some studies suggest sodium and/or potassium ionic channels are directly altered, reducing membrane excitability while others suggest it interacts with SV2 protein to alter synaptotagmin's (a calcium sensor protein) action in the presynaptic nerve terminal and reduce excitability. The glutamatergic synapses at crayfish and larval Drosophila neuromuscular junctions (NMJs) were used to assess the drug's action. The evoked excitatory junction potentials (EJPs) of the crayfish NMJ were enhanced by exposure to 1 mM, but not lower doses

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within 20 min of stimulation after static incubation for 10 min. However, no significant alterations were noted in the amplitude of the EJPs at the Drosophila NMJ for 1 mM over 20 min while stimulating the NMJ at 5 Hz. The crayfish model and the effects of levetiracetam was used as an authentic undergraduate research experience (ACURE) in a neurophysiology teaching laboratory with 16 students. It appears levetiracetam acts differently in different animal models or varied experimental conditions are required to note its effects.

P27-2 McPherson, SM*; Agugliaro, J; Farrell, TM; Lind, CM; University of New England, Biddeford, ME, Fairleigh Dickinson University, Madison, NJ, Stetson University, DeLand, FL, Stockton University, Galloway, NJ; *smcpherson2@une.edu*

Ophidiomycosis, but not reproductive status, is associated with reduced post-capture glycemic response in pygmy rattlesnakes (Sistrurus miliarius)

Challenges to homeostasis, including threat of predation, elicit an acute adrenal response in vertebrates and cause reallocation of energetic resources. The magnitude of the mobilization of energy substrates (e.g. glucose) in the blood plasma may depend on individual energetic status or competing physiological processes. In viviparous snakes, the physiological state of pregnancy and coping with emergent fungal pathogens may result in significant energetic costs to individuals and force tradeoffs that impact the adrenal response to acute stress. We tested the hypotheses that pregnancy and ophidiomycosis attenuate the mobilization of glucose in response to short-term capture stress. In summer 2019, blood samples were drawn from pregnant and non-reproductive pygmy rattlesnakes upon capture (pre-stress) and again after 30 minutes of handling and confinement (post-stress). Plasma glucose concentrations were measured using a point-of-care glucometer (FreeStyle Lite®, Abbott, USA). All snakes were swabbed for qPCR detection of *Ophidiomyces ophiodiicola* (*Oo*), the causative agent of ophidiomycosis, and cloacal body temperatures were recorded. Effects of reproductive status and ophidiomycosis on the change in glucose concentration (post-stress minus pre-stress) and post-stress glucose concentration were analyzed using separate ANCOVA models including cloacal body temperature as a significant

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covariate. While glycemic response did not differ significantly by reproductive status, both measures of glycemic response were significantly lower in *Oo*-positive snakes. This reduction in glycemic response to acute stress may have long-term fitness implications for snakes with ophidiomycosis.

P40-1 Mehlhorn, AE*; Donatelli, CM; Hall, KC; William and Mary, Williamsburg, University of Ottawa, Ontario, University of Washington, Friday Harbor Labs; *aemehlhorn@email.wm.edu*

The curious case of chimaera kinematics: gait transitions in the spotted ratfish (Hydrolagus colliei)

Gait change, or the transition from one mode of locomotion to another, has been described in both terrestrial vertebrates (walk to run) and bony fish (fin flap to body undulation). However, little is known about gait transition in cartilaginous fish. Here we describe a gait change in a holocephalan chondrichthyan, the Spotted Ratfish (*Hydrolagus colliei*), which has been observed swimming with playing movements of its pectoral fins. While previous studies have classified *H. colliei* as labriform swimmers, we recorded a diversity of swimming patterns. To quantify aquatic gait, we placed *H. colliei* (N = 6) in a saltwater flume at speeds ranging from 0.1-0.8 body lengths per second (BL/s). We point tracked swimming video clips to determine pectoral fin, pelvic fin, and tail beat frequencies and amplitudes. Based on these data, *H. colliei* has three distinct gaits beginning with a pectoral undulation that gives way to oscillatory pectoral flapping and pelvic movement. At high swim speeds, *H. colliei* transition to whole body undulation. Anterior to posterior fin beat amplitudes characterize the transition from undulatory to oscillatory fin movements. The pectoral and pelvic fin beat frequencies increase linearly with swim speed from 0-0.3 BL/s, then maintain the same frequency from 0.3-0.5 BL/s, and increase linearly again from 0.5-0.8 BL/s. Tail beat amplitude nearly doubles at 0.6 BL/s, while pectoral and pelvic fin amplitudes decrease over increasing swim speeds. Thus, the first gait transition seems to occur between 0.3 and 0.5 BL/s and the second at 0.6 BL/s. By analyzing gait changes in *H. colliei*, we can begin to understand the complex kinematics of deep sea chondrichthyans.

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P40-4 Meja, B*; Notar, JC; Johnsen, S; Duke
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Insects go with flow: A mathematical model of induced flow and cooling during flight
The flapping of insect wings allow them to hover and maneuver in their environments. These flapping movements create a strong induced flow of air over their bodies, which is a critical aspect of their ability to fly and it also plays a critical role in thermoregulation. Thermoregulation is crucial for insects' ability to fly because their flight muscles require certain temperatures in order to maintain sufficient power in flight. The study of induced flow has advanced our overall understanding of the aerodynamics of insects but one cannot say the same about thermoregulation. To study how induced flows affect thermoregulation in flight, we created a mathematical model of a generic hovering insect, using simple shapes such as a sphere or cylinder to see how induced flow affects cooling across a range of parameters, including wingbeat frequency and body angle relative to its wings. We then related these parameters to the natural body and flight characteristics of bumblebees (*Bombus terrestris*) and honey bees (*Apis mellifera*). We studied which parameters were most relevant for the bee's thermoregulation. Results will be discussed.

P23-11 Merges, H*; Goddard, K; Ursinus
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Combined effects of temperature and salinity on the coral, Astrangia poculata
Astrangia poculata is a temperate species of coral found along the East Coast of North America, ranging from Massachusetts to the Gulf of Mexico. It has a facultative relationship with its zooxanthellae and, unlike many tropical species of coral, does not need to be inhabited by zooxanthellae to remain healthy; it can survive solely on food obtained by suspension feeding. I am studying the effect of decreased salinity and increased temperature on the health of *A. poculata* from the Gulf of Mexico (Florida) and Buzzards Bay (Massachusetts). While other studies have examined the effect of temperature on *A. poculata*, the impacts of both decreased salinity

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and increased temperature have not been extensively studied. This question is particularly important because we are simultaneously seeing an increase in global sea surface temperatures and an increase in the intensity and frequency of storms. These storms can lower salinity in coastal waters where *A. poculata* are found. I am slowly increasing temperature over time from 18° C to approximately 30° C and lowering the salinity from 35 ppt to about 15ppt. The controls are held at a constant of 18° C and 35 ppt, which are considered optimal conditions for this species. Some colonies are subjected to the change in temperature, others exposed to the change in salinity, and some are exposed to combined increased temperature and decreased salinity. *A. poculata* health is measured through the number and density of zooxanthellae, which are counted using a hemocytometer on a fluorescent microscope at 400x, the color changes associated with zooxanthellae loss, and polyp death. For asymbiotic polyps, growth is measured throughout the experiment as a determinant of health. This research project will help to fill the knowledge gap regarding the temperature and salinity tolerances of *A. poculata*.

P9-7 Mesrop, LM*; Goodheart, JA; Minsky, G; Oakley, TH; University of California, Santa Barbara , University of California, San Diego ; *lmesrop@ucsb.edu*

Characterizing the genetic origin of novelty in a charismatic non-model system: bioluminescent ostracods ('sea fireflies')

Throughout their evolutionary history, organisms have evolved a myriad of novel complex traits, increasing survival and reproductive success. However, the evolutionary history of these novel traits is often difficult to document. To understand the genetic origins of novel complex traits, we use a gene co-expression network-based approach to identify genes responsible for the origin of a novel trait - bioluminescence in Cypridinid ostracods. Sea fireflies emit light-producing compounds from a light organ and use bioluminescence for both anti-predator defense and courtship signals. The light reaction involves a substrate, luciferin, and an enzyme, luciferase, each of which is synthesized in separate gland cells and discharged in a mucous-like substance. Here, we aim to identify gene candidates responsible for the synthesis of luciferin, a molecule with a fundamental and defined

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functional role in light production behaviors. We hypothesize that genes involved in the luciferin biochemical pathway and production of secreted mucus are co-regulated with luciferase in response to specific stimuli, such as defense or courtship signaling. We generated transcriptomic profiles of the bioluminescent ostracod, *Vargula tsujii*, under various physiological and environmental conditions. 53,409 genes were selected for weighted gene co-expression analysis and highly co-expressed genes were divided into 100 modules. In the co-expression module containing luciferase, we identified genes that encode mucous-like proteins with VWD domains and venom-like cysteine-rich proteins and endopeptidases. Future work will add expression data from multiple bioluminescent ostracods to facilitate the identification of candidate genes in the luciferin biochemical pathway.

P38-7 Miladin, JR*; Steven, JC; Collar, DC; Christopher Newport University; *jenna.miladin.17@cnu.edu*

Direct and indirect influences of climate on pollination and floral morphology

Diversification of pollinator syndromes in plant lineages potentially involves the influence of both climate and pollinators. Colonization of new habitats during lineage evolution may result in shifts in pollinator community that drive adaptive changes in floral morphology. Habitat shifts may also lead to changes in climatic niche, and floral traits may change in response to new abiotic conditions. To evaluate these influences on flower evolution, we tested associations between environmental niche variables and vegetative and floral morphology in the genus *Silene* using phylogenetic comparative methods. We collected DNA sequence and morphological data for 70 *Silene* species; 17 species were collected from the field in Greece, and 53 species from the same taxonomic sections were added with data from Genbank and morphological measurements of herbarium specimens. We estimated phylogeny based on Bayesian analysis and used GBIF occurrence records to determine climatic niche for each species. Flower color-white or pink-was used as a proxy for pollinator. We found that species with white flowers tend to experience a narrower temperature range during the day and exhibit longer internodes and larger flowers. These results suggest that abiotic conditions

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restrict nocturnal pollination. In addition, we found links between leaf morphology and climate; smaller leaves are associated with habitats that have greater mean temperatures and less precipitation in the summer. But these associations were not apparent for floral morphology. Altogether, our results suggest that abiotic habitat directly influences vegetative morphology, but its effects on flower morphology are likely mediated through shifts in pollinator community.

P12-6 Mitchell, DR*; Menegaz, RA; University of North Texas Health Science Center; *Rex.Mitchell@unthsc.edu*

From pellets to palates: harder foods make hardier heads among post-weaning rats

The impact that the material properties of foods have on the mammalian skull has been studied extensively. However, research that compares cranial morphology and biomechanics in response to dietary shifts during growth is limited. Here, we present preliminary analyses comparing Sprague-Dawley rats raised on contrasting post-weaning diets. We employed shape analysis (geometric morphometrics) and computational biomechanics (finite element analysis) to quantify the impact of food hardness on the morphology of developing rat crania. Four groups of rats were fed different diets from weaning (week 4) to adulthood (week 16): powdered pellets only (SS); hard pellets only (HH); powdered pellets followed by a switch to hard pellets at week 10 (SH); and hard pellets switched to powdered pellets. We found significant differences in cranial shape between SS and HH groups, and SH and HH groups. In both cases, similar shape differences were found in the region of the temporal zygomatic root, suggesting that a diet of hard foods may have a consistent impact on morphology. Biomechanical modelling demonstrated clear differences in bone stress distributions during incisor biting between an HH cranium and a SS cranium. The HH model experienced less stress across the anterior neurocranium, posterior muzzle, and palate, indicating that a higher degree of bone remodeling and reinforcement has likely taken place during development in response to a diet of harder foods. These findings suggest that juvenile diets are an important predictor of intraspecific cranial morphology. More extensive analyses incorporating larger sample sizes will help to

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further elucidate the nature of these relationships and will contribute to our understanding of mammalian osteology and mastication, post-weaning development, and orthodontics.

P37-8 Mitchell , L*; Taglialatela, J; Guindre-Parker , S; Kennesaw State Univeristy, Kennesaw, GA; *lauren0806@gmail.com*
Social dynamics in bonobos: Using cortisol to measure stress response with the introduction of a new group member
For social animals, group living can serve to buffer against stressors. However, changes in the social environment may also represent stressors, and social conditions have been linked to changes in glucocorticoids in many taxa. We studied glucocorticoids in captive bonobos (*Pan paniscus*), a social species with complex social organization. We sought to understand how bonobo individuals respond to changes in their social environment, and how these responses differ with dominance rank. We monitored bonobos before, during, and after a change occurred in their social environment, where a new group member was introduced at the captive facility. We repeatedly sampled individuals' cortisol (corrected for creatinine) from urine samples using enzyme immunoassays. Using these results, we will investigate whether changes in cortisol concentrations occurred during the introduction of the new group member. Results from this study will provide insight into how bonobos respond to changes in group dynamics. This work is also important to inform animal welfare and management practices, where changes in social dynamics can be driven by caretakers rather than initiated by animals in the social group.

P33-10 Mo, A*; Izzi, F; Haeufle, DFB; Badri-Spröwitz, A; MPI for Intelligent Systems, Stuttgart, University of Tübingen; *mo@is.mpg.de*
Viscous damping in legged locomotion
Damping likely plays an essential role in legged animal locomotion but remains an insufficiently understood mechanism. Intrinsic damping in muscle can regulate joint torque, stabilize movements, and reject perturbations. Recently, legged robots started exploring model-based, virtual damping. However, this control mechanism requires high-frequency force control loops, precision sensing, and

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high-power actuators. Legged animals are, in comparison, 'handicapped' due to inherent sensorimotor noise, nerve conduction delay of their 'wetware', and lower 'computational power'. Alternatively, physical damping in robots can simulate intrinsic damping in muscle to achieve instantaneous action, sensor-free response, and adaptive force output (Mo et al, 2020). It is so far unexplored how physical damping can be deployed for locomotion tasks. Here we utilize a robot leg drop experiment to capture core aspects of legged locomotion: negotiating ground contact in the presence of uncertainties, with physical damping mounted in-parallel to a tendon-like structure (a spring). We also studied the energy dissipation from viscous and Coulomb damping in a numerical leg model, under equivalent conditions. These simulation results indicate that adjustable and viscous damping is indeed a desirable characteristic. The hardware experiments showed that adjusting the damper's setting did not substantially alter the effectively dissipated energy per drop, unlike in the numerical model. Still importantly, effective viscous damping was achieved under various initial conditions, and fully characterized with the help of the sensorized robot leg drop setup. This effective damping has the potential to increase robustness in locomotion without the need for computation or sensing.

P9-4 Mojica, EA*; Fu, Y; Kültz, D; University of California, Davis; *eajarett@ucdavis.edu*

Identification of histone post-translational modifications in three tissues of Mozambique tilapia (Oreochromis mossambicus)

Histone post-translational modifications (PTMs) are epigenetic marks that modify the state of chromatin and lead to alterations in gene expression. Advances in mass spectrometry have enabled the high-throughput analysis of histone PTMs without the need for prior knowledge of individual PTMs of interest. In this study, the global histone PTM landscape was analyzed in the gills, kidney, and testes of Mozambique tilapia (*Oreochromis mossambicus*) through tandem mass spectrometry using data dependent acquisition (DDA-LCMS2) and PTM mapping approaches. PTM assignment to a specific amino acid was validated using A-score and localization probability scores that are based on the detection of diagnostic MSMS ions. These values signify the robustness of PTM assignment to a specific residue

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within the protein sequence. For PTMs that were represented by both modified and unmodified versions of the corresponding peptide, the stoichiometry was calculated and compared between tissues. We have identified multiple types of histone PTMs and assigned them to specific residues in each tissue. These PTMs include acetylation, methylation, demethylation, trimethylation, phosphorylation/dehydration, and ubiquitination. Our results indicate that the gills, kidney, and testes each display a unique profile of histone PTMs. These data provide a strong basis for the generation of spectral libraries that enable high-throughput quantitative analyses of histone PTM stoichiometry on a global scale in tilapia exposed to diverse environmental and developmental contexts. This study is supported by NSF award 1656371.

P41-5 Moncrieffe, TE*; Crandell, KE; Bangor University; *tomosmoncrieffe@gmail.com*

Substrate compliance improves locomotor performance in the Mongolian gerbil (Meriones unguiculatus)

Animals moving across granular media such as desert sand are challenged by reduced friction and increases in substrate compliance. Compliant granular media have the unique property of both solid and semi-liquid states. Here kinematics of self-motivated *Meriones unguiculatus* (Mongolian gerbil) are investigated on four granular substrates of various compliances, ranging from 0.25 mm up to 8mm in diameter, and one flat control substrate. Gerbils demonstrated higher maximum velocity on fine- (1.17 m^s-1) and intermediate-sized sandy substrates (1.10 m^s-1) compared to the non-compliant control substrate (0.95 m^s-1) (n = 9 gerbils, 4 trials each, ANOVA p<0.05). Particle properties of the two intermediate substrates of different particle sizes (0.23-0.6 mm vs. 0.57-1.4 mm diameter) had similar load-bearing capacity (0.7 N cm^-2) and bulk density (1.6 g ml^-1), and similar performance was observed in both (ANOVA p=0.54). The kinematics of gerbil runs also demonstrated the possibility of compensatory behaviours - by both hindlimb displacement and hopping frequency. The largest substrate particles (8mm) yielded lower average hop distances (0.1 meters vs. 0.13 meters) and overall maximum velocities (1.06 m s^-1 vs 0.95 m^s-1), compared to control treatment. Preliminary analyses suggest that gerbils may switch between a hop with both hindlimbs in

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tandem, and offsetting the hindlimbs, to modify overall velocity. Lower overall running performance on the non-compliant (flat ground) and highly compliant substrate suggest that gerbils might be optimised for naturally compliant substrates within a certain range.

P2-3 Moore, J*; Bock, S; Bertucci, E; Bae, J; Parrott, B; Benedict College, University of Georgia, Augusta University; *Samantha.bock@uga.edu*

Interactive effects of ecologically relevant temperature regimes and p,p'-DDE exposure on patterns of gonadal gene expression in the American alligator (Alligator mississippiensis)

In the face of a rapidly changing global climate, it is important to understand how thermal fluctuations and contaminant exposure interact to influence wildlife health. Species with temperature-dependent sex determination (TSD) may be especially vulnerable to the adverse effects of these anthropogenic influences due to their profound environmental sensitivity during development. In this study, we examine the interactive effects of ecologically relevant temperature regimes and embryonic exposure to the organochlorine pesticide metabolite, *p,p'*-DDE on the reproductive development of the American alligator (*Alligator mississippiensis*), a species with TSD. During incubation, alligator embryos were exposed to one of five thermal regimes - a constant female-promoting temperature (30°C), a constant male-promoting temperature (33°C), a constant intermediate temperature (31.2°C), or a fluctuating temperature regime based on empirically derived nest temperature profiles with an amplitude of either ±0.6°C or ±2.8°C around a mean of 31.2°C. At developmental stage 19, eggs were topically exposed to a vehicle control or one of two doses of *p,p'*-DDE (low dose, 0.1μg/g egg weight; or high dose, 1μg/g egg weight). Levels of circulating plasma sex steroids and gonadal expression patterns of genes involved in sex determination and reproductive development were examined in 10-day old alligator hatchlings. Effects of temperature and contaminant exposure on patterns of inter- and intrasexual variation in neonatal alligators provide insight into the persistent consequences of interacting anthropogenic stressors experienced during development in a wildlife model.

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P10-10 Moore, AJ; Stony Brook University, Stony Brook, NY; *andrew.j.moore@stonybrook.edu*

(Almost) the same at any size: Scaling of the axial skeleton in herons (Ardeidae)

Whereas the numbers of vertebrae making up different regions of the axial skeleton exhibit substantial variation between major clades of birds, counts of cervical, thoracic, and synsacral vertebrae are relatively constant within major clades of birds. This limited within-clade variability in vertebral number requires that any allometric scaling of vertebral regions be accomplished by differential vertebral growth, rather than variation in somite number. Differential growth of the axial skeleton has been demonstrated in non-avian clades with limited variation in vertebral number, but similar patterns have yet to be documented within major avian clades. Here, I assess scaling of the axial skeleton in herons (Ardeidae), which exhibit a constant number of cervical (17) and thoracic (6) vertebrae across a greater than 10-fold range in body mass. Phylogenetically-informed regression analyses show that the length of the cervical series scales isometrically with body size in herons - a pattern recently demonstrated for crown birds generally - and find that the lengths of the thoracic and synsacral series, as well as the vast majority of locus-specific linear measurements, also scale with isometry. In addition, neck length scales isometrically with skull length and leg length, but shows positive allometry in relation to thorax length. The predominance of isometric growth in herons is consistent with the hypothesis that a pneumatic and lightly built skeleton allows somatic growth to occur without substantial allometric compensation. Future work can test this hypothesis by comparing patterns of axial scaling in pneumatic clades to those of clades lacking skeletal pneumaticity (e.g. penguins; cormorants).

P26-6 Moore, H J*; Bischof, K; McClelland, S; Wheeler, M; States, S; Freeman, P; Woodley, S; Duquesne University, Phipps Conservatory and Botanical Gardens; *moore.haleyjo@gmail.com*

Characterizing Coqui frogs in Phipps Conservatory and Botanical Gardens

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Billions of pounds of chemicals are used annually to control pests, despite concerns for human, wildlife, and ecosystem health. However, public gardens have long been champions of non-chemical pest control methods. In 2008, 18 male and female Coqui Frogs (*Eleutherodactylus coqui*) were introduced to Phipps Conservatory and Botanical Gardens as a means of pest control. Coqui Frogs are small terrestrial frogs from the neotropics that breed year-round in suitable conditions. To determine the viability of this captive population, we analyzed population size and reproductive activity using exhaustive captures and male calling, an indicator of mating. Environmental parameters and frog morphology were also recorded. Since their initial introduction into a single room, the Coqui Frogs have expanded to 3 additional rooms. Using data from exhaustive captures, and assuming a 1:1 male to female ratio, there are at least 50 adult Coqui Frogs currently in Phipps, indicating population growth. We observed calling year-round with a positive relationship between calling and outside temperature and humidity. This study provides new insights into the breeding patterns and expansion of an unmanaged, captive population of frogs, opening opportunities of mark recapture studies using VIE tagging.

P32-3 Morales-Vega, E*; Eshleman, MRA; Klug, PE; López-Martínez, G; Young, R; Björn , W; Greives, TJ; North Dakota State University, USDA-APHIS-WS, NWRC, Institute of Environmental Change and Society; *esther.moralesvega@ndsu.edu*

Assessing telomeres as a potential marker of the cost of migration in red-winged blackbirds

Living in seasonal environments has its challenges. Temperate breeding birds migrate to southern regions during fall to avoid winter conditions. Birds return to breeding grounds following spring to take advantage of local resources to feed their offspring. Although annual migration has benefits, it also has associated costs. High metabolic activities may result in by-products that cause oxidative damage to DNA, and consequently shorten telomeres, the protective structures at the end of chromosomes. Therefore, telomere attrition could be influenced by the distance traveled during annual migration. In this study we aim to (1) test the hypothesis that telomere loss is related to migratory distance between non-breeding and breeding grounds, and

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(2) examine relationships among oxidative damage, migratory distance, and telomere loss. Telomere loss will be assessed as the difference between telomere length of captured red-winged blackbirds (*Agelaius phoeniceus*) in 2018 and after recapture in 2019. Oxidative damage will be measured as malondialdehyde (MDA) concentration in blood plasma. To determine migratory distance, we used hydrogen stable isotopes from distal claw samples, which estimate the bird's overwinter latitude. We predict (1) higher telomere loss in long-distance migrants compared to shorter-distance migrants, (2) females, who travel farther, will have higher telomere loss than males, and (3) oxidative damage will be positively correlated with migratory distance and telomere loss. These data will increase understanding of trade-offs between traveling farther to more favorable overwinter conditions and the associated costs.

P19-6 Morris, JS*; Rogers, N; Rogers, AR; Carrier, DR; Wofford College, University of Utah; *morrisjs@wofford.edu*

Big female heads and big male bodies: sexual dimorphism in skeletal shape in voles

Sexual dimorphism often evolves as a response to sexual selection on musculoskeletal traits that improve a male's ability to compete for access to mates. In addition body mass, adaptations to specific anatomical components that increase strength, stability, and agility may also improve fighting performance. We tested the hypotheses that male voles, as compared to females, are more specialized for fighting performance in their skeletal anatomy and that the degree of sexual dimorphism increases with the intensity of male-male competition. In three species of voles with different mating systems, we found partial support for these hypotheses. In the postcranial anatomy, we found male-biased sexual dimorphism in several skeletal shape indices associated with improved fighting performance. Consistent with predictions, this dimorphism was greatest in the polygynous *Microtus californicus*, absent in the monogamous *Microtus ochrogaster*, and intermediate in the promiscuous or socially flexible *Microtus oeconomus*. In the skull, however, we found results opposite to our predictions. Relative to overall skeletal size, females had larger skulls than males. Larger heads in females may be associated with selection for increased

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food processing efficiency, which may be highly important because of the compounding effects of increased food intake requirements during gestation and lactation, and the generally low-quality diet of voles. Larger heads in females may also be associated with selection for improved digging performance (voles use their incisors to dig) or for defending offspring. These results suggest disparate selective pressures on the skulls and postcranial skeletons and of female and male voles.

P15-1 Musulman, AM*; Coutts, VM; Wada, H; Auburn University , Auburn University; *akm0050@auburn.edu*

Examining neophobia and startle behavior in response to nutritional stress during development

Animals respond and cope with stressors by eliciting physiological and behavioral responses. Much research on stress responses has focused on physiological responses while behavioral responses to a stressor are relatively understudied. Furthermore, young animals whose neural and physiological systems are undergoing development and maturation are most susceptible to stressors, yet long-term effects of developmental stressors on behavior are largely unknown. Using zebra finches (*Taeniopygia guttata*) as a model organism, we tested how nutritional stress during development may be linked to neophobia and startle behavior later in life. Control and nutritional stress nests were paired together in order to determine the amount of food the stress nests received. Control nests had ad libitum access to seeds while stress nests received 65% of the seed consumed by their paired control nest to induce nutritional stress. Treatment was given from 5 to 60 dph, and behavioral trials were conducted between 97 and 117 dph. For object neophobia, birds were placed in individual cages and recorded interacting with two different objects attached to their food bowl, with a plain food bowl to measure their response without a novel object. Videos were then analyzed for latency to approach 3.5 cm from the food bowl, the food bowl, and to feed. For the startle test, birds were given a plain food bowl for 15 seconds, then a hand was placed into each individual cage and immediately removed to startle the birds (approximately 1 second). The latency to feed after startle was analyzed. In the startle test, nutritionally stressed females had a significantly higher latency to feed than control females, with no

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effect in males. Currently, the rest of the videos are being analyzed for latency measurements.

P5-2 Nazarian, LA*; Bukovich, IMG; Parker, MR; James Madison University, Harrisonburg, VA; *nazarila@dukes.jmu.edu*

Redesigning the quantification of reptile behavior in Y-mazes

The Y-maze is a powerful tool used for more than 50 years to understand reptile chemical ecology across a range of biological questions. For most Y-maze experiments, the primary method of cataloguing behaviors is first choice, which is when the reptile's head passes some predetermined point in an arm of the Y. While first choice is a valuable piece of information, choice alone poorly informs behavioral studies; a myriad of environmental factors that impact the Y-maze trials go unquantified, yet if included in data analyses could yield a more accurate representation of behavior. We are applying the use of Y-mazes to assess the ability of Burmese pythons (*Python bivittatus*) to follow the scent trails of conspecifics in the Florida Everglades, and specific behaviors (i.e., head shakes, pauses, turns, head raises, tongue-flicking, time spent in each arm) of focal snakes will be examined through long-span video. Behaviors will be analyzed up until first choice then accounted for across the entire trial. We have developed a novel protocol for quantifying the amount of scent deposited by a scenting/stimulus snake as well scoring focal snake movement as it explores the maze. For initial phases involving the scent-laying snake, this "scent score" is used as a covariate; if there is a disproportionate amount of scent laid in the arm, trailing snake behavior should reflect this. Identifying new strategies for using covariates in behavioral analyses is critical for strengthening the validity of our interpretation of reptile behavior in future studies.

P17-2 Negron-Pineiro, LJ*; Di Gregorio, A; New York University College of Dentistry; *adg13@nyu.edu*

Cis-regulatory control of stage-specific notochord gene expression by Brachyury

The notochord is an embryonic structure of mesodermal origin that functions as a signaling center and structural support for the

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surrounding embryonic tissues. The functions of evolutionarily conserved notochord transcription factors (TFs) and of the cis-regulatory modules (CRMs/enhancers) that coordinate expression of their effectors during notochord development are still largely uncharacterized. Our lab uses an invertebrate chordate, *Ciona robusta*, to unravel the notochord gene regulatory network and to characterize structure and function of notochord CRMs. The TF Brachyury is a main evolutionarily conserved regulator of notochord development. Despite being expressed specifically and continuously in the notochord throughout all the stages of its development, *Ciona Brachyury* (Ci-Bra) is somehow able to regulate the staggered deployment of early-, middle- and late-onset notochord genes, and to coordinate the transcription of genes involved in sequential steps of notochord morphogenesis. Through the systematic characterization of Ci-Bra-downstream notochord CRMs, we have formulated a mechanistic hypothesis to explain how temporal information is encoded within Ci-Bra-downstream notochord CRMs. We are testing this hypothesis in light of recently published ATAC-Seq chromatin profiles, with the help of bioinformatic tools. The regulatory role of Brachyury during notochord evolution is remarkably conserved among species that diverged over 500 millions of years ago. Thus, studying the cis-regulatory strategies employed by Ci-Bra will inform research on notochord formation in more complex chordates.

P23-1 Nenstiel, R*; Donahoe, C; Hranitz, JM; Surmacz, C; Bloomsburg University; *csurmacz@bloomu.edu*

Assessing sublethal stress in honeybees exposed to "bee-friendly" neonicotinoid and pyrethroid pesticides

Honey bees (*Apis mellifera*) contribute to worldwide agricultural pollination. Since 2006, bee pollinators have experienced global declines, which may be linked to widespread agricultural use of neonicotinoid pesticides and a phenomenon known as colony collapse disorder (CCD). While CCD appears to be caused by many factors, neonicotinoid pesticides are indicated as a major factor in CCD. Neonicotinoids and pyrethroids differ in their chemical structure and strategies for application. We tested honey bees in acute exposure to two neonicotinoid (imidacloprid, acetamiprid) pesticides and one pyrethroid (deltamethrin) pesticide for

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sublethal motor coordination and stress responses. Motor and cellular stress responses (superoxide dismutase (SOD) activity) were measured after 4-h exposure to treatments. Control bees were fed 1.5 M sucrose and treatment groups were fed sublethal doses ($1/5^{th}$ LD_{50} to $1/500^{th}$ LD_{50}) of pesticides in 1.5 M sucrose. Doses were similar to those reported for the natural environment. After treatment, we evaluated the movement of the abdomen, legs, antennae, and proboscis extension reflex and calculated motor scores. Bees displayed impaired motor coordination at $1/5^{th}$–$1/10^{th}$ LD_{50} when fed imidacloprid and at $1/5^{th}$ LD_{50} when fed with acetamiprid. Deltamethrin did not impact motor coordination at the doses used in our study. Bees displayed increased SOD activity at $1/5^{th}$–$1/10^{th}$ LD_{50} treatments of imidacloprid but no difference in SOD activity among acetamiprid or deltamethrin treatments. This suggests acetamiprid and deltamethrin are safer to honey bees than imidacloprid.

P30-5 Neurohr, JM*; Simpson, SK; Kinsey, ST; UNCW; *jmn6284@uncw.edu*
Microplastics translocate to hemolymph and increase standard metabolic rate in the blue crab, Callinectes sapidus
The impact of microplastics (MPs; < 5 mm diameter) on physiological processes is becoming an increasing concern in organisms inhabiting coastal and estuarine areas. Many marine organisms spend large portions of their life in these habitats, exposing themselves to MPs via respiration and consumption. It has recently been documented that MPs can be translocated to organs, impact physiological processes, and alter behavior although these consequences appear to be species specific and dependent on MP size. This study aims to determine the physiological consequences of MPs on the recreationally and commercially important blue crab, *Callinectes sapidus*. *C. sapidus* were exposed to water column concentrations of microplastics (average 2 μm diameter) at a concentration of 1 $x10^{6}$ particles L^{-1} for a period of 120 h. Water was replaced daily to replenish the microplastic concentration. After 120 h, standard metabolic rate (SMR) was assessed via resting oxygen consumption rate. Microplastic translocation to hemolymph, hepatopancreas, gills, digestive tract, and swimming muscle was assessed via tissue digestion and epifluorescence microscopy. After 120 h of MP exposure, crabs had a significantly higher SMR than

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those not exposed to MPs. Additionally, MPs were found to translocate to the hemolymph of crabs with an average concentration of 1.16 x 10^{-3} mg/ml. This translocation was verified via microscopy. These results indicate that blue crabs are susceptible to physiological impairments from microplastics. This may have a profound influence on the animal's daily energy budget, which could have ecological consequences.

P34-2 Newcomb, JM*; Jordan, T; Luke, GP; Hoppa, MB; New England College, Dartmouth College; *jnewcomb@nec.edu*

Minimally invasive neural stimulation via ultrasound and piezoelectric nanoparticles

Current methods of neural stimulation suffer from limitations for *in vivo* use in humans. Ultrasound offers high spatial and temporal resolution, great penetration depth, low scattering in tissue, and is noninvasive. Furthermore, pairing ultrasound with piezoelectric nanoparticles can enhance sensitivity. The purpose of this study was to demonstrate the feasibility of adhering barium titanate nanoparticles (BTNPs) to the plasma membrane of neurons and ultrasound stimulation of these BTNPs to induce firing in both cultured neurons and in an isolated brain preparation. BTNPs were electrically poled, modified to be water-soluble and biocompatible, and conjugated to fluorescent markers. They were then applied to cultured rat hippocampal neurons, where they were effectively targeted to the plasma membrane. Without BTNPs present, neurons exhibited a calcium response to electrical stimulation, but not focused ultrasound pulses. In contrast, after addition of BTNPs, ultrasound pulses elicited glutamate release and a calcium response similar to electrical stimulation. Additional experiments using brains isolated from the sea hare *Aplysia californica*, indicated that BTNPs also adhered to the plasma membrane of these neurons. Ongoing studies are investigating the effects of ultrasound pulses, both with and without BTNPs, in this *ex vivo Aplysia* brain preparation. Together, these data demonstrate that BTNPs can adhere to the plasma membrane of target cells and, when paired with focused ultrasound, may noninvasively facilitate excitation of neurons.

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P33-1 Nguyen, KD*; Venkadesan, M; Yale University; *khoi.nguyen@yale.edu*

Filament compliance and the perturbation response of active sarcomeres

Activated muscle applies forces in response to its stimulus but also when mechanically perturbed. The temporal characteristics of decay in stresses due to step perturbations are key to characterizing the mechanical response. If stresses are long-lived, muscle is stiff like an elastic solid and could be used in posture maintenance tasks. But if stresses are rapidly dissipated, muscle yields like a viscous liquid and could be used for rapidly changing posture. We show by modeling muscles as half-sarcomeres with cycling crossbridges on a compliant filament backbone that filament compliance leads to an increase in the stress relaxation time compared with a rigid backbone. The slowdown depends on a single dimensionless ratio l/p of the filament overlap l to a length scale p that arises from a partitioning of strain between the filament backbone and crossbridges. In living muscle, this parameter would be varied by the mean number of attached crossbridges so that greater activation implies a greater value of (l/p). The relaxation time constant is nearly constant for l/p << 1, but increases nonlinearly as (l/p)^2 when (l/p)>>1. We estimate (l/p)>5 for mammalian sarcomeres with a 10x slowdown of stress relaxation. The physical basis lies in interactions between crossbridges. With a compliant filament, the attachment of one crossbridge distorts neighboring crossbridges and induces changes in its kinetics. Many muscle models thus far have assumed a rigid filament backbone, which prevents this mode of cooperativity. Thus, the effects introduced by filament compliance may be a possible mechanism underlying a muscle's ability to maintain an elastic behavior on timescales much longer than crossbridge cycling. These effects may scale up to the whole fiber based on titin that mediates inter-sarcomeric interactions.

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P6-5 Nguyen, C*; Huang, I; Peleg, O; University of Colorado Boulder, University of Colorado Boulder and Santa Fe Institute; *chantal.nguyen@colorado.edu*

Modeling evolution of firefly-like signal vocabularies during species radiation

Fireflies in vast swarms communicate with each other by producing bioluminescence to signal their presence and court mates. In particular, some species emit patterns of short flashes that have the potential to encode information. Male fireflies flash according to a species-specific pattern in order to attract and locate female partners. As multiple firefly species can share the same habitat, potential visual clutter could greatly hinder species discrimination and successful communication among conspecifics. We investigate how firefly flash sequences can co-evolve to be distinguishable by developing a method for simulating flash patterns that minimizes a cost function which incorporates similarity and predation risk. We observe an emergent periodicity in the resulting optimal sequences despite the lack of any constraints on the sequences to contain regular patterns. We also demonstrate a method of reconstructing potential cost functions from the phylogenetic relationships of extant species alongside their characteristic flash patterns.

P3-2 Niebur, T*; Putney, J; Sponberg, S; Georgia Institute of Technology; *tniebur3@gatech.edu*

Motor output in hawk moths is encoded at the millisecond-scale across all muscles

Major sensory inputs to animal nervous systems are encoded at the millisecond scale in a temporally precise code. Until recently, the role of precise timing in muscle activation and motor output was underappreciated. Animals from moths to birds to mice have been shown to control motor behavior using precise spike timing, but we largely do not know at what scale timing matters in motor systems. Work in *Drosophila* and *Manduca sexta* has shown sub-millisecond timing differences cause changes in power output, providing evidence in a few systems and muscles that precise timing is important. However, the question remains unanswered whether individual muscles receive information encoded on different timescales, or if the timescales remain consistent across the muscle set. We recorded simultaneous turning (yaw) torque output and EMG recordings from the 10 primary muscles of *Manduca sexta* as tethered moths visually tracked a robotic flower moving with a 1 Hz sinusoidal trajectory. we measure the precision of neural spikes used to encode information about movement. We show through two

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complementary information theoretic methods, including a novel noise corruption method, that the scale of temporal precision in all muscle activations is comparable to many sensory systems. All parts of the motor program encode information at the single millisecond-scale and this scale is consistent across all muscles. This precise timing must either be deconstructed and then reconstructed by the sensorimotor system or is preserved through the system.

P5-10 O'Neill, EA*; Davis, HE; MacMillan, HA; Carleton University, Ottawa, ON; *ericaoneill@cmail.carleton.ca*

Does basal cold tolerance constrain plasticity in individual Drosophila?

Thermotolerance is a major determinant of ectotherm geographic distribution, but the physiological mechanisms underlying cold tolerance remain poorly understood. A critical uncertainty is whether basal thermotolerance constrains plastic thermotolerance, such that animals with greater basal tolerance have a lower capacity for acclimation. To address this question, a trade-off between basal and plastic thermal tolerance has been tested at several levels in insects (e.g. lineage, species, and population), often with conflicting results. If basal tolerance constrains plasticity through shared mechanisms of tolerance, however, it should be evident at the level of the individual over multiple trials, provided the trait measured is repeatable. Here, we used chill-coma onset temperature (CCO; a non-lethal thermal limit) to quantify cold tolerance of individual *Drosophila melanogaster* across two trials (pre- and post-acclimation). Overall, cold acclimation significantly improved cold tolerance, as expected. However, measurements of CCO in control flies (that were not cold-acclimated) were not repeatable and yet, surprisingly, degree of plasticity was still related to basal tolerance. We argue that this relationship is an artefact of the most common method for testing for such trade-offs and does not reflect a true trade-off or physiological constraint. More broadly, our data suggests that cold tolerance traits (or at least CCO) lack the intraindividual repeatability necessary to test for thermal plasticity constraints at this level. Altogether, our work supports previously voiced concerns about common practices for testing tolerance-plasticity

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trade-offs, and we propose a new approach for addressing these questions.

P2-2 Olivares-Zambrano, D*; Aguilar, A ; Hyde, J ; California State University Los Angeles, Los Angeles, CA, NOAA Southwest Fisheries Science Center, La Jolla, CA; *doliva13@calstatela.edu*
Finding the right home: Depth as a driver of speciation in the genus Sebastes
This project aims to identify genomic regions that have contributed to ecological differentiation among recently diverged Northern Pacific species pairs from genus Sebastes. We expect depth segregated speciation to result in selective sweeps that generate islands of genomic diversification. We have sequenced exomes from S. chlorostictus-S. rosenblatti and S. crocotulus-S. miniatus. The former pair is more recently diverged (0.21 Ma) while the latter pair diverged longer ago (2.3 Ma). Species pairs that are more recently diverged should have more numerous but distinct genomic islands due to the recency of their divergence and contemporary gene flow. Species pairs that are more divergent should have fewer and less recognizable genomic islands across their genomes. The average exome wide Fst (a measure of population differentiation) for S. chlorostictus-S. rosenblatti was 0.02 while the average exome-wide Fst for S. crocotulus-S. miniatus. was 0.07. Although exome wide average Fst values are relatively low for both species pairs, they both shared chromosomal regions with elevated Fst values. Finally, nonsynonymous (dn) and synonymous (ds) substitutions were estimated between species pairs to identify loci under positive (dn/ds > 1), neutral (dn/ds = 1) or purifying (dn/ds < 1) selection. Out of 24,093 genes, 1329 genes showed positive selection for S. chlorostictus-S. rosenblatti and 1224 genes showed positive selection for S. crocotulus-S. miniatus. These results provide insight into genomic impacts on speciation in the marine environment.

P23-10 Oraha, GR*; Burnaford, JL; California State University, Fullerton, Fullerton, CA; *goraha@csu.fullerton.edu*
Hanging by a thread: Investigating the effect of low tide temperature on mussel attachment strength

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Mytilus californianus, the California mussel, is a foundation species and dominant space-holder in the rocky intertidal zone, an environment that goes through extreme temperature shifts on a daily basis as organisms are submerged in seawater during high tide and exposed to terrestrial conditions during low tide. Mussels create protein 'anchors' called byssal threads that allow them to attach to rocks and each other. Previous work has examined how wave action negatively affects mussel attachment. Yet to date, few studies have addressed the role of temperature during low tide on attachment strength of mussels, despite the clear importance of this topic in the context of the rising temperatures predicted with a changing climate. We used laboratory manipulations to investigate how temperature during low-tide affects three components of mussel attachment: byssal thread production, individual mussel attachment strength, and single byssal thread strength. We collected mussels from two southern California field sites and set up a fully factorial seven-day experiment with two types of treatments: number of low tide exposures (exposure on the first day followed by six days of submersion or exposure each day for seven days) and temperature during low tide exposure (ambient or elevated temperature). In the elevated temperature treatment, we used small heaters to individually raise body temperatures by XoC. We predicted and have found that mussels exposed to natural ambient treatments generally have greater individual mussel attachment strength and single byssal thread strength than mussels exposed to elevated temperatures.

P21-3 Ortega-Jimenez, VM*; Seleb, BR; Wilson, LG; Mendelson, JR; Bhamla, S; Georgia Institute of Technology, Zoo Atlanta, Zoo Atlanta; *ornithopterus@gmail.com*

Feeding upside down: Hydrodynamics of filter-feeding in flamingos

Flamingos are renowned for their highly specialized filter-feeding system in water, comprising their uniquely shaped beak and tongue structures. Using this filtering system, in concert with vertical head oscillations and lateral movements, these birds can effectively filter micro-particles from muddy waters. It is known that these birds pump water in-and-out using their tongues as a piston pump to trap particulate matter in their beak's lamellar structures (filters). However, the role of flow perturbations

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generated by flamingo's head oscillations on particulate retention and filtration remains unclear. Thus, the goal of this talk is to describe how flamingos exploit hydrodynamics to influence particulate retention. We conduct experiments with captive flamingos (*Phoenicopterus chilensis*) at Zoo Atlanta using a custom-built setup. This setup enables us to capture the kinematics of the head as well as 2D Particle Image Velocimetry (DPIV) of the fluid flow during filter-feeding. We further use a 3D-printed biomimetic model of the flamingo head, to conduct laboratory experiments to establish the role of the beak oscillation frequency and amplitude on the biophysical fluid dynamics of filter-feeding. Together, this study will shed new insights on how self-inflicted flow perturbations effect particle retention in one of nature's extraordinary filter-feeding birds.

P29-4 Ouillon, N*; Sokolov, EP; Jarret, A; Sokolova, IM; University of Rostock, Germany , Leibniz-Institute for Baltic Research, Warnemuende, Germany; *natascha.ouillon@uni-rostock.de*

The influence of different oxygen regimes on bioenergetics of a soft shell clam Mya arenaria

Hypoxia is common in the coastal zone requiring physiological adaptations in the benthic sessile organisms to cope with this condition. A lack in oxygen could affect mitochondrial function that accounts for 90% of ATP production and impair energy-dependent functions such as locomotion and bioturbation. We exposed the soft shell clams *Mya arenaria* for 21 days to chronic (1.78 O_2 mg/mL), fluctuating (5.46-0.82 O_2 mg/L) hypoxia, or normoxia (9.16 O_2 mg/mL). To mimic conditions occurring in coastal hypoxic zones, CO_2 and pH levels varied with the oxygen. We assessed their digging performance, bioirrigation capacity and bioenergetics. Clams acclimated to chronic or fluctuating hypoxia dug slower and/or shallower than their normoxic counterparts. Furthermore, bioirrigation capacity decreased in clams acclimated to chronic hypoxia. Chronic hypoxia led to a decrease in the lipid content of the clam tissues whereas acclimation to the fluctuating hypoxia resulted to accumulation of proteins and carbohydrates compared to the normoxic clams. Exposure to the fluctuating (but not chronic) hypoxia led to an increase in the mitochondrial proton leak and reactive oxygen species production resulting in a higher

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maintenance cost of the mitochondria. Our results indicate that chronic and fluctuating hypoxia impair digging performance of clams and might negatively affect predator escape and bioturbation activity. Fluctuating oxygen conditions also appear to be more damaging to the clams' mitochondria than the chronic oxygen deficiency.

P4-2 Palecek-McClung, AM*; Huie, JM; Cohen, KE; Donatelli, CM; Summers, AP; Clemson University, Clemson, SC, George Washington University, Washington, DC, University of Washington, Friday Harbor, WA, University of Ottawa, Ottawa, ON, University of Washington, Friday Harbor, WA; *apalece@g.clemson.edu*

Stuck on you: How pelvic girdle morphology influences adhesion

Pelvic suction discs have independently evolved multiple times in bony fishes. The discs are used to adhere to substrates during climbing or station-holding and show tremendous diversity in musculoskeletal morphology and performance. These suction discs vary in size, texture, the substrates they are used on, and their internal skeletal morphology. We compared how the shape of the pelvic girdle contributes to adhesive performance in four groups of bony fishes- clingfishes, gobies, snailfishes, and lumpsuckers. We used CT data to make 3D printed models of pelvic girdles and embedded each model into a standardized silicone suction cup. We measured the pull-off forces on 3 substrates varying in surface roughness. Generally, bioinspired suction cups followed comparative live-animal adhesive performance trends, and performance increased as surface roughness increased. Though the clingfish (*Gobiesox*) has the highest performing suction disc in nature, its suction cups yielded poor adhesive performance. Most fishes with suction discs have a modified pelvic girdle, but clingfish suction discs are supported by both pectoral and pelvic girdle elements. Our low clingfish values are likely due to the absence of the pectoral girdle skeletal elements. We have established that this simple modeling technique will track the real world results of pull off tests for suction performance. We will now use the technique to explore the finer scale diversity of skeletal support structures in fishes. This is especially interesting work in light of the immediate biomimetic implications on manufactured suction devices.

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P18-8 Paravasthuramesh, A*; Neiman, M; Stipp, C; Pope, A; University of Iowa, Humboldt State University; *aparavasthuramesh@uiowa.edu*

An ecological investigation of cancer in a prostate cancer cell model

This project integrates ecological and evolutionary principles to investigate the basis of cancer metastasis, with a particular focus on potential ramifications for cancer progression of tumor cell heterogeneity. That tumor cell heterogeneity can play a critical role in cancer progression is clear, but the underlying evolutionary forces and ecological mechanisms as well as the cell-specific drivers remain important open questions. By using growth competition experiments under controlled conditions using model cell lines (prostate cancer lines PC-3E and GS689), we hope to obtain new insights that can be more broadly applied to understand the effect of tumor cell heterogeneity on tumor evolution. The parental cell line is a heterogenous population containing both cells with epithelial and mesenchymal phenotypes. We conducted a series of competition experiments with the following starting ratio variations of epithelial to mesenchymal: 50:50 (as done in preliminary experiments), 90:10, 75:25, 10:90, 25:75, and 92:8 to test the density-dependent effect on the proliferation of mesenchymal cells in the presence of epithelial cells. This set of experiments suggests a density-dependent ability of GS689 to slow the growth of PC-3E cells. Our observations are consistent with a hypothesis that GS689 cells produce one or more concentration-dependent factors that suppress the growth of the PC-3E cells, resulting in the elimination of PC-3E cells when GS689 cells are present in a high proportion and perhaps retention of GS689 cells via local growth suppression of neighboring PC-3E cells, when GS689 cells start out at a lower proportion. This may help to explain how mesenchymal cells have persisted in the parental population.

P33-8 Parikh, AS; McInroe, BW*; Full, RJ; Univ. of California, Berkeley; *bmcinroe@berkeley.edu*

Mole crab inspired robot and simulation models reveal limb scaling and coordination principles for legged burrowing

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A growing number of tasks require subterranean locomotion and sensing, including infrastructure inspection and soil characterization. However, the design and control challenges of burrowing into flowable, complex substrates have limited the development of bioinspired burrowing devices. To begin to develop design and control principles for multifunctional burrowing robots, we explore the burrowing biomechanics of the Pacific mole crab, *Emerita analoga*, which uses its appendages to swim, crawl, and rapidly burrow into intertidal substrate. Experiments on physical robot analogs of *E. analoga* motivated the development of a large N-body granular simulation model built on the Project Chrono physics engine to quickly model and test morphological and control parameters. We find that design parameters such as relative limb lengths have a strong effect on depth reached and the angle of intrusion. Analysis of the connection between internal shape velocities and vertical intrusion velocity reveals a periodic relationship between the phase of limb rotation and the stages in the burrowing process. The active phases expand the burrow, raising the robot, and then excavate the substrate behind the robot, moving it deeper during excavation and continuing into the recovery phase. Upward slips occur when limbs are expanding the substrate during active power strokes, and effects are amplified when both limb groups are in the same phase. The simulation environment is parameterized and reconfigurable to facilitate further studies of diverse body morphologies and controllers, and results can guide the design of novel legged burrowing robots.

P41-9 Pehl, K*; McElroy, E; College of Charleston; *pehlka@g.cofc.edu*

The relationship between locomotor performance and habitat use in six-lined racerunners (Aspidoscelis sexlineata) in coastal South Carolina

A fundamental question in ecology is how organisms are distributed in time and space. A critical determinant of this distribution is an animal's locomotion because it affects multiple tasks that impact its fitness, including defense, dispersal, finding mates, foraging, and escaping from predators. Locomotion can be affected by the structural complexity of a habitat, obstacles, and escape strategies. This study examines the relationship between locomotor

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performance and habitat use in Six-Lined Racerunners (*Aspidoscelis sexlineata*) and will answer three questions: (1) Do Racerunners use their habitat randomly or non-randomly? (2) How does "available" habitat affect Racerunner locomotion? (3) Is the pattern observed in question #1 explained by question #2? We use habitat data collected via transects from Sullivan's Island, South Carolina, and observations of Racerunners to quantify which substrates they run on in their natural habitat. To determine how available habitat affects locomotion, we conducted a lab experiment where Racerunners were placed on a racetrack covered in sand and/or debris and examined the acceleration, speed, and behavior that occurred during each trial. We then compared field habitat use to differential running performance and behavior in the laboratory.

P27-10 Perrine, WG*; Love, AC; Morris, AN; DuRant, SE; The University of Arkansas; *wgperrin@uark.edu*

Diet macronutrient composition affects disease pathology in Serinus canaria infected with Mycoplasma gallisepticum

Individual macronutrients in the diet contribute to immune processes and the immune system's ability to efficiently clear an infection. Some studies have shown that infected animals will consume protein to enhance survival, while other studies have shown that lipids can reduce inflammation and increase antibody production. By altering the ratios of specific macronutrients, the interplay and individual impact they have on immune responses can be better understood. Using an avian host-pathogen system and isocaloric diets, I explored the effects of dietary macronutrient composition, specifically lipid and protein content, on disease pathology and behavior of canaries (*Serinus canaria*) infected with *Mycoplasma gallisepticum* (MG). Female canaries provided a protein-rich diet, whether infected or not, consumed more calories per week than female canaries on a lipid-rich diet. Also, all birds that were infected exhibited illness-induced anorexia in the first week post infection. Infected birds also experienced a significant decline in fat scores and body mass post infection. Diet did affect disease pathology; infected birds on the lipid diet experienced clinical signs of infection (swollen eye conjunctiva) longer than birds on the protein diet, as measured by eye score. Despite these differences in eye score over time, post-infection levels of MG

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specific antibodies were not significantly different between infected birds fed the different diets. These data indicate that diet macronutrients could play an important role in individual variation in disease severity among hosts infected with a pathogen. These data suggest that host diet could affect pathogen growth and reproduction, and thus, disease transmission. Future plans include estimating pathogen load in birds used in this study.

P40-2 Phillips, QP*; Karra, P; Minicozzi, MR; Minnesota State University, Mankato; *qpp2@nau.edu*

A precise and cost-effective fish flume for assessing swimming performance in fishes

Zebrafish are a commonly used vertebrate model organism for issues related to genetics, ecotoxicology, and development. Being able to accurately measure swimming performance in fishes is crucial to understanding their development and physiology. Research quality fish flumes often come at high price which is not ideal for a primarily undergraduate university where research is not the focus. Because of this, we have designed and built a research quality fish flume to test novel research questions related to swimming performance. We designed our flume with two spherical-impeller pumps, connected in series, with the option to summon one or both pumps programmatically. Our flume also utilizes a modulating control valve which is needed to achieve low flow rates. The flume utilizes an Omega flowmeter capable of providing relatively high resolution. Flowrate is controlled through a closed-loop PI (proportional-integral) control scheme implemented using myRIO (National Instruments) that is transferable to any system with the same controller, even with some variation in other components of the system. Our flume can achieve flow rates between 0-40 cm/s with data recorded every 100 ms or faster, depending on flowrate. All flumes experience some degree of variance in flow when attempting a target flow rate. This is to be expected as the computer records immediate flow rate and adjusts the output of the pumps accordingly. With our flume, we achieved very precise flow rates (+/- 0.06 cm/s), limiting the amount of variance around the set rate of flow. To show that our flume works, we investigated swimming performance in zebrafish. The design and control of this flume will be kept open source such that those in a research

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setting are able to replicate this work and build a quality budget machine for analysis of swimming performance in fishes.

P24-3 Piechocki, C*; Liang, N; O'Reilly, S; Brianik, C; Bopp, J; Cerrato, R; Allam, B; Stony Brook University; *camilla.piechocki@stonybrook.edu*

Insufferable bookworms and their crabby victims: Quantifying the infection intensity of flatworms on horseshoe crab book gills

The American horseshoe crab (*Limulus polyphemus*) is a marine arthropod that serves crucial economic and ecological roles and is currently experiencing regional declines. Declines are attributed to overharvest, but there is limited knowledge regarding the impacts that natural stressors impose on horseshoe crab fitness, especially symbiont interactions. Therefore, we quantified the prevalence and intensities of the parasitic flatworm (adult and cocoon stages), *Bdelloura candida*, on the gills of *L. polyphemus*. Adult (n=29) and juvenile (n=30) horseshoe crabs were collected in Moriches Bay, NY in June 2019. *B. candida* was prevalent in all adult crabs (100%), whereas, juveniles exhibited 0% prevalence. To quantify infection intensity, gill sections (10%) were removed from adult crabs and *B. candida* cocoons were enumerated and measured to quantify the respiratory surface area occupied by the parasites. A positive correlation between adult worm intensity and number of cocoons was observed, whereas crab size did not explain the variation of worm intensities (R^2>.23). Cocoon intensities per sample ranged from 28 to 805, with 4-94% of gill lamellae harboring cocoons. In infected individuals, the total cocoon surface area on gill tissues was variable as it ranged from 0.06% to 14.51% and infection intensity was positively correlated with gill surface area (ρ=0.45, p = 0.01). High infection rates may negatively affect gill functioning in *L. polyphemus*. Our results provide novel insight into *B. candida* infection dynamics, but further research is necessary to quantify the physiological impacts of the infection on *L. polyphemus*.

P30-8 Piechowski, JM*; Bagatto, B; The University of Akron, Akron, Ohio; *jmp310@zips.uakron.edu*

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Cardiovascular function during early development is suppressed by nicotine-free, cinnamon flavored, electronic cigarette vapor
Despite a recent surge in vaping related lung illness and an overall lack of research regarding the health implications associated with their use, electronic cigarettes and vaping devices have continued to remain popular among teens and young adults since their introduction to the United States over a decade ago. The popularity of these products among those of childbearing age necessitates research on the potential impact of maternal vaping on embryonic function during development. Here, we examined the effects of nicotine-free, cinnamon, or chocolate, flavored vapor on cardiovascular function during early development using the zebrafish model. Flavored electronic cigarette vapor was produced from a second-generation vaping device and was infused into dechlorinated water at high, medium, and low concentrations. Vapor infused water was distributed among flasks to which zebrafish embryos were added within 4 hours post fertilization. Videos of the heart and blood vessels were recorded at 24 hours post exposure and cardiovascular parameters were measured to assess the effects of cinnamon, or chocolate, flavored vapor on cardiovascular function. At high exposure concentrations, cinnamon flavored vapor significantly inhibited cardiovascular function while chocolate flavored vapor did not, thus indicating that cardiovascular function in the developing embryo may be affected in a flavor dependent manner, even in the absence of nicotine. The results of this study provide much needed data on the potential impact of flavored, nicotine-free, electronic cigarette vapor on cardiovascular function during early development which may occur as a result of maternal vaping during pregnancy.

P22-5 Postupaka, D*; Le, E; Svensson, K; Uhm, C; Ellerby, DJ; Wood, BM; Wellesley College, MA; *dpostupa@wellesley.edu*
Habitat-specific foraging strategies and polymorphic variation of bluegill sunfish, Lepomis macrochirus
As generalists, Bluegill Sunfish (*Lepomis macrochirus*) feed in densely vegetated littoral and pelagic zones. Paradoxically, being a generalist requires that Bluegill adopt habitat-specific foraging strategies in order to successfully exploit local environments. To better understand their foraging behaviors, underwater cameras were

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deployed in different locations of Lake Waban, MA to reflect the diversity of local habitats within the lake. We identified three foraging strategies: hunting, grazing, and pelagic feeding. Each strategy is categorized as opportunistic or intentional and some are further subdivided into several modalities. Hunting occurs in shallow littoral zones, is intentional, often performed in groups, and is characterized by repeating cycles of burst-coast-stop-search until prey is visually detected. Grazing also occurs in shallow littoral zones, but is either intentional or opportunistic, and is characterized by three modalities depending on vegetation type. Active grazing involves biting and pulling on pondweed, whereas passive grazing involves hovering near milfoil and delicate suction feeding, and surface grazing involves searching beneath lily pads and explosive bouts of suction feeding. Pelagic feeding occurs in deep open water, is often opportunistic, may occur in groups, and is characterized by intermittent swimming from one morsel to the next. Some correlation exists between phenotype, age, and foraging strategy. For example, darker and deeper bodied adults engage in hunting, whereas lighter and fusiform Bluegill of all ages engage in pelagic feeding. These observations demonstrate the complex behaviors that characterize a paradigmatic generalist and illustrate the multitude of variables that impact their specific feeding strategies.

P21-5 Potter, B*; Corrales-Ugalde, M; Townsend, JP; Colin, SP; Sutherland, KR; Costello, JH; Gemmell, BJ; University of South Florida, Tampa, FL, University of Oregon, Eugene, OR, Providence College, Providence, RI, Roger Williams University, Bristol, RI, Providence College, Providence, RI; *potter7@usf.edu*

Ubiquitous yet inconspicuous: quantifying trophic impact of a widespread oceanic comb jelly (Ctenophore)

The oceanic lobate ctenophore *Ocyropsis spp.* has a widespread distribution throughout tropical and sub-tropical oceans. While patchy, *Ocyropsis spp.* can be abundant with densities exceeding one individual per m^3. However, little is known about the trophic impacts of these animals and differences in habitat and prey capture mechanisms on zooplankton prey (copepods) prevent the use of data from coastal species. In this study we used high-resolution videography and imaging in the field and laboratory to record

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interactions of *Ocyropsis spp.* with copepod prey to quantify feeding ability. We found that *Ocyropsis spp.* uses a unique combination of muscular lobe contraction and prehensile mouth movement for prey capture. Mean capture success was 71% when a single copepod was present and 40% when multiple prey were present within the ctenophore lobes. Gut content analysis showed that *Ocyropsis spp.* consume significantly more prey at night, leading to higher gut fullness at night. We found that copepods are digested within 44.19 (± 10.45) minutes with no relationship between ctenophore size and the average digestion time. Based on our findings, conservative estimates show that population densities of 3.3 *Ocyropsis spp.* individuals per 1000 m^3 could consume 100% of the daily standing stock of copepods in Atlantic oceanic waters. The implications of this study suggest that oceanic ctenophore species have the capacity to exert strong top down control of zooplankton stocks.

P4-3 Poulin, E*; MacLeod, L; Kolmann, MA; University of Washington, University of Michigan Museum of Paleontology; *empoulin@uw.edu*
The versatile skulls of herbivorous fishes: the functional morphology of pacu and piranhas jaws and teeth
The Serrasalmidae are a family of Neotropical freshwater fishes that includes carnivorous piranhas as well as their herbivorous relatives, the pacus. Pacu diets consist of leaves, stems, fruits, seeds, and algae, as well as insects, benthic invertebrates, plankton. Likewise, some piranha species are actually more omnivorous than carnivorous, feeding on fruits and seeds in particular and only to a lesser degree the fins and scales of other fishes. These diverse prey materials appear concomitant with diverse jaws and dentitions in both pacus and piranhas, suggesting that some species are ecomorphologically specialized for feeding on certain prey. We investigated how the pattern and tempo of feeding morphological specialization in herbivorous serrasalmids reflects the ecological diversity of their food resources. Pacu and piranha species were first categorized as either algivores, frugivores, folivores, phytophages, planktivores, or omnivores based on a meta-analysis of published gut content data. We used computed tomography (CT) scanning and morphometrics to describe the primary morphological axes of jaw and dental variation and any correlates

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these phenotypes may have with each species' primary prey. We found significant differences in the occlusional offset, mechanical advantage, size and shape of the lower jaw among different diet guilds. Phytophages tended to have scissor-like dental occlusion, resembling piranhas more than other pacus. We also found significant differences in the rate of morphological evolution among different diet guilds, notably folivores had morphological rates over 40 times faster than that of planktivores, suggesting different selective regimes acting on each dietary guild.

P22-4 Puitiza, A*; Jacobson, S; Synder, R; Sheppard, A; Plotnik, J; CUNY Hunter College, New York, CUNY Graduate Center, New York, Oklahoma City Zoo and Botanical Garden, Oklahoma City, Rosamond Gifford Zoo, Syracuse, New York, CUNY Hunter College, New York and CUNY Graduate Center, New York; *amanda.puitiza@macaulay.cuny.edu*
Exploring predictors of problem-solving and innovation ability in captive Asian elephants
Asian elephants in the wild and captivity adapt well to changing environments, with the former often facing increasing conflict with humans due to habitat loss. To investigate how behavioral traits and social access may explain behavioral flexibility in elephants, we studied captive Asian elephants in zoos to identify behavioral measures of problem solving and innovation. We presented six elephants in Oklahoma and eight in Syracuse with an extractive foraging device comprised of three compartments over two testing phases. The first phase device had three 'push solution' doors to establish a learned solution for each subject. The second phase device consisted of three different-solution doors (push, pull and slide). Across both locations, eight elephants solved the entire device, three solved two doors, and three solved only one door. There was no significant difference in problem-solving success across sex ($U = 19.5$, $p = .685$), origin ($U = 17.5$, $p = .720$), and zoo location ($U = 19$, $p = .513$). Latency to solve the first door decreased for eleven of the elephants in their second session, possibly as a result of learning. Latency to first ever contact, our neophilia score, ranged from 0.755 to 88.746 seconds, but did not correlate with success ($r= .382$, $p= .246$). We will also present variance in motor diversity and the elephants' typical social

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groupings, as well as discuss implications that this study may have for human-elephant conflict mitigation.

P23-8 Rahman, MS*; Rahman, MS; University of Texas Rio Grande Valley, Brownsville, TX, University of Texas Rio Grande Valley, Brownsville, TX ; *md.sadequr.rahman@vanderbilt.edu*

Elevated seasonal temperature disrupts prooxidant-antioxidant homeostasis and promotes cellular apoptosis in the american oyster, Crassostrea virginica: a field study

Rising seawater temperature induces heat stress in marine organisms, particularly in the marine invertebrates, due to their poikilothermic nature. In this study, we observed changes in tissue morphology, extrapallial fluid (EPF, a body fluid) pH, and the expression of heat-shock protein 70 (HSP70), dinitrophenyl (DNP, an indicator of oxidative stress and ROS), 3-nitrotyrosine protein (NTP, a biomarker of nitrative stress and RNS), catalase (CAT, an antioxidant enzyme), and superoxide dismutase (SOD, an antioxidant enzyme) in the gills and digestive glands of American oyster collected from the southern Gulf of Mexico coast during winter (15oC), spring (24oC), summer (30oC), and fall (27oC). Histological analysis showed increased mucus secretion in both tissues along with the enlargement of lumina in digestive glands; whereas, immunohistochemical analysis showed an increase in HSP70, DNP, and NTP expressions with rising seasonal temperatures, suggesting high seasonal/seawater temperatures cause heat-induced oxidative and nitrative stress in oysters. This was concomitant with a significant decrease in EPF pH and elevated cellular apoptosis in oyster tissues. Interestingly, the expression of CAT and SOD also increased from winter to spring and in fall; however, a significant drop was observed in summer, indicating oyster tissues become defenseless against ROS and RNS mediated oxidative and/or nitrative damage at high seawater temperatures leading to elevated cellular apoptosis. Collectively, we conclude that high seasonal temperatures cause heat-induced oxidative and nitrative stress that disrupts the prooxidant-antioxidant homeostasis leading to increased cellular apoptosis in oysters.

P34-1 Ramirez, MD*; Tait, C; Katz, PS; University of Massachusetts

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Using hybridization chain reaction for reliable, large-scale mapping of neurons in the brain of the nudibranch, Berghia stephanieae

Molecular work on "non-traditional" organisms is limited by a lack of specific antibodies and probes for mapping expression of proteins and genes. Hybridization Chain Reaction (HCR) and RNA-seq make reliable, large-scale mapping of neurons more accessible by expanding the pool of potential gene products that can be labeled for almost any animal. We have introduced the nudibranch *Berghia stephanieae* as a new species for neuroscience research because it has a small brain that can be mapped in its entirety. Here, we used both traditional immunohistochemistry (IHC) and HCR to map the expression of neurotransmitter-related genes to neurons in the *Berghia brain*. We reproducibly labeled populations of neurons positive for 9 genes: serotonin, small cardioactive peptide, FMRFamide, conopressin, egg-laying hormone, choline acetyltransferase, tyrosine hydroxylase, APGWamide and GABA. Some genes, such as egg-laying hormone, conopressin and tyrosine hydroxylase, the synthetic enzyme for catecholamines, were expressed in only a small and discrete set of neurons. Others, such as choline acetyltransferase, the synthetic enzyme for acetylcholine, were widely expressed. HCR is a fluorescent technique, allowing us to simultaneously label up to 5 genes. We have also combined HCR with IHC in the same sample. Using these techniques we found co-expression of neuropeptides with each other, but other neurotransmitter-associated genes did not overlap in expression. HCR enables broader molecular studies of unorthodox animals and comparisons of gene expression, neurons and brains across the animal phylogeny.

P25-3 Rej, J*; Deery, S; Gunderson, A; Tulane University, New Orleans, LA; *jrej@tulane.edu*

Microclimate and physiological plasticity interact to determine overheating risk of competing native and invasive Anolis lizards

Invasive species cause substantial adverse effects to native wildlife, and there is great interest in understanding what makes invasive species successful. The lizard Anolis sagrei is a successful invasive species along the Gulf Coast of the United

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States, where they have displaced the native A. carolinensis. We predicted that A. sagrei's success is due to their ability to endure higher temperatures. In this study, we compared performance of the two species in different microclimates to see if A. sagrei has an advantage over A. carolinensis under high temperatures. To estimate performance, we applied a biophysical model to calculate field operative temperatures for every hour over the past 25 years of A. sagrei's Gulf Coast invasion. From the model, we predicted the threat of overheating for each species in full sun and shade. Additionally, heat hardening data were incorporated into the overheating model to determine if plastic responses contributed to differences in overheating risk between species. Heat hardening provided a clear advantage to A. carolinensis in open microhabitats, decreasing their annual overheating hours by an average of 36%. In contrast, A. sagrei did not heat harden; prior heat exposure decreased their heat tolerance and increased their susceptibility to overheating. Shaded microhabitats were important for both species to avoid overheating, providing operative conditions that rarely exceeded their heat tolerance limits. Collectively, these results suggest that A. carolinensis is better able than A. sagrei to tolerate the extreme heat present in their shared environment. As annual temperatures continue to rise, A. sagrei will face a greater threat of lethal temperatures which could benefit A. carolinensis in habitat reclamation.

P25-1 Reynolds, JA*; Bryant, C; Ohio State University; *reynolds.473@osu.edu*

Do microRNAs mediate the response to cold stress in the flesh fly, Sarcophaga bullata?

During the winter insects face numerous challenges including low temperatures, limited food, and lack of available water and oxygen. These challenges are met, at least in part, by molecular adaptations that reduce metabolic rate and alter cellular structures to prevent tissue damage. Accumulating evidence suggests that microRNAs, small noncoding RNAs that postranscriptionally regulate gene expression, have a significant role mediating the molecular response to winter stresses in insects. This study investigates the possible contribution of microRNAs toward cold tolerance in the flesh fly, *Sarcophaga bullata*, an established

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model for studying rapid cold hardening and cold shock. Quantitative PCR was used to measure changes in the abundance of candidate miRNAs (miR-277, miR-13, miR-124, miR-31, miR-1, miR-33, miR-92, miR-190, miR-275, miR-33) after red-eye pharate adults were chilled at 0 ° C for 2 h and allowed to recover at 25 ° C for 2 h. None of these miRNAs were significantly different immediately after cold shock compared to control flies kept at 25 ° C. After 2 h of recovery both miR-13b-3p was upregulated by 1.5-fold compared to the cold shock and the control groups (P = 0.04), but other miRNAs evaluated in this study remained unchanged. Though these miRNAs are differentially regulated in Colorado potato beetles, *Leptinotarsa decemlineata*, in response to cold stress (Morin et al. 2017 Insect Mol Biol; 26:574) they do not seem to have a critical role in cold tolerance in flesh flies. Additional studies are necessary to determine whether miRNAs do not have a role in cold stress in flesh flies or if the suite of miRNAs that respond to cold is unique for each insect species.

P40-6 Richards, CT*; Moen, DS; The Royal Veterinary College, Oklahoma State University; *ctrichards@rvc.ac.uk*

Modelling the relationship between frog morphology and swimming performance over multiple kicking cycles

Despite their distinct body form, frogs show considerable diversity in traits that affect locomotion, including swimming. While frog swimming has often been mathematically modelled, many approaches are abstract and include parameters that do not directly relate to anatomical measurements on real specimens. On the other hand, other models are too complex and cannot be easily generalized for broad taxonomic comparisons. Towards a framework for linking morphology and performance across a diversity of anurans, we developed a model that allows for broad explorations of body and limb morphology whilst minimizing the number of parameters. All model parameters map explicitly to anatomical measurements that can be gathered from specimens or literature. The power stroke is driven by a Hill-type muscle representing the lumped hindlimb extensor muscles driving the translational and rotational foot movements. The recovery stroke is modelled kinematically to allow the legs to kick at various user-defined swimming frequencies, mimicking the range seen among species. In a preliminary exploration, we varied cycle

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frequency from 1 to 9 Hz while also varying the surface area of the webbed feet. Both ranges of variation were based on our previously collected data from a broad diversity of species. Mean swimming velocity over multiple strokes showed a parabolic relationship with frequency, with maximum speed at ~5 Hz. Over an eightfold increase in foot size, speed increased more sharply at low versus high cycle frequencies. Further simulations will be required to evaluate how foot and body morphology interact with swimming strategy to dictate swimming performance.

P27-11 Richards, KM*; Cline, NW; Burgess, EL; Brothers, CJ; Walla Walla University, College Place, WA, Burman University, Alberta, Canada; *kallan.richards@wallawalla.edu*

Seagrass wasting disease severity in the Salish Sea

Seagrasses are found in dense meadows along the coastline and provide essential ecological and economic benefits. However, seagrass meadows are also one of the most threatened ecosystems on the planet, and outbreaks of seagrass wasting disease (SGWD) may be contributing to the decline of seagrass meadows in the Pacific Northwest. SGWD is caused by the marine protist *Labyrinthula* spp. which produces dark necrotic lesions, reduced photosynthetic activity, and eventual plant mortality. The pathogen is abundant in the marine environment, but anthropogenic impacts such as nutrient pollution may make seagrass meadows more vulnerable to *Labyrinthula* spp. infection. We surveyed seven intertidal seagrass meadows (*Zostera marina*) in the Salish Sea during summer 2019. At each site, we quantified disease incidence (% of plants displaying necrotic lesions) and severity (% of leaf covered in lesions) from photographs using Image J. Both the incidence (2-96%) and severity (0-9%) of disease was significantly different across sites. The incidence and severity of disease was highest at Padilla Bay, WA which also possessed the highest seawater nitrate levels. In the laboratory, plants were held under low and high levels of nutrient pollution (nitrate and phosphate) for 30 days before being inoculated with *Labyrinthula* spp. and the progression of SGWD was observed. Seagrass exposed to high nutrient levels displayed significantly more SGWD than seagrass exposed to low nutrient levels, suggesting eutrophication may be one factor influencing the severity of SGWD.

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P22-2 Ricker, TA*; Zlotnik, S; Miller, CW; University of Florida, Gainesville; *tessa.ricker@ufl.edu*

Juveniles do not use adult feeding sites in the leaf-footed bug, Narnia femorata

Access to nutritional resources is limited for juvenile herbivores that feed on plants with well-developed structural defenses, such as a thick shell surrounding a nutrient-rich seed. In aggregative species, juveniles may take advantage of the food processing behaviors of larger conspecifics to facilitate access to limited food resources. This hypothesis has not been well-tested in herbivores that feed on structurally defended plants despite their important role in both natural and agricultural systems. Juvenile herbivores often lack the fully developed feeding morphology of their adult conspecifics and thus may depend on adults to damage the host plant's feeding barriers. We examined whether juvenile leaf-footed cactus bugs, *Narnia femorata* (Hemiptera: Coreidae), use this strategy when feeding on cactus fruits that were previously fed on by adult conspecifics. We hypothesized that juveniles would feed in the same locations as adults, allowing them to use the semi-permanent stylet sheaths created by the adults during feeding to access nutrients within the seeds at the center of the fruits. To test this hypothesis, we marked where adults fed on fruits and then placed juveniles on the same fruits to determine the location of their feeding in comparison to that of the adults. We found no evidence that the juveniles take advantage of the stylet sheaths created by adults to facilitate their feeding. It is likely that other feeding adaptations in juvenile herbivores, such as mouthpart plasticity, play a larger role in gaining access to nutrients essential for development and survival.

P15-7 Rivas, MG*; White, KJ; Pradhan, DS; Idaho State University; *rivameli@isu.edu*

The plasticity of social status: systemic stress hormones in a hermaphroditic fish

Psychosocial stress due to dominance rank can have profound effects on physiology, behavior, and metabolism. Cortisol, a glucocorticoid that controls stress-induced responses in all vertebrates, may be

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an important mediator of changes in behavioral phenotype due to social structure or changes in status, such as dominance and/or subordinate rank. Bluebanded gobies, *Lythrypnus dalli*, are bidirectionally hermaphroditic fish, in which sex change occurs due to a change in social structure. In stable groups, *L. dalli* live in linear social dominance hierarchies, such that one male dominates over many females and defends a nesting territory. Upon male removal (MR), the most dominant female exhibits rapid increases in rates of aggressive and territorial behavior. This species is ideal for exploring the effect of social status and instability on cortisol levels due to the plasticity of life history transitions, such as sex change. Here, we compared systemic cortisol levels amongst the group hierarchy in stable groups, 30 min after MR, and 24 h after MR. Behavioral observations were taken in 10 min bins and used to determine the status of each fish in a group. There was no significant difference in water-borne cortisol levels in stable groups or after MR. These data indicate that systemic cortisol levels are not a good indicator of rapid changes in *L. dalli* following a disruption in social status. We anticipate to better understand the role of cortisol in stable groups and after MR as we study local mechanisms of cortisol signaling that are independent of systemic levels. Future studies will investigate more specific measures from the brain, such as cortisol, cortisol producing enzymes, or glucocorticoid receptor levels.

P28-3 Roberts, NG*; Kocot, KM; University of Alabama, University of Alabama Museum of Natural History; *ngroberts@crimson.ua.edu*

Developing a contaminant-aware pipeline to resolve lophotrochozoan relationships in the genomics age

The animal superphylum Lophotrochozoa exhibits the greatest disparity of body plans in the animal kingdom, ranging from giant squid to microscopic worms. Among these are the charismatic Mollusca (e.g., snails, and octopus), the medically important Platyhelminthes (e.g., human schistosomiasis), and the familiar Annelida (e.g., earthworms) among many more. Resolving evolutionary relationships within Lophotrochozoa has been difficult due to their likely ancient and rapid radiation. Furthermore over half of the phyla within Lophotrochozoa are microscopic making obtaining the necessary amounts of high molecular weight DNA challenging. Recent

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advances in molecular biology have made it possible to obtain high quality transcriptomes from a single meiofaunal animal. However, as the entire animal must be used for DNA/RNA extraction, multiple sources of contamination (e.g., gut contents, epibionts, and symbionts) are sequenced as well. These contaminants can be challenging to detect, but are potentially important contributors of non-phylogenetic signal. We are developing a contaminant-aware workflow for phylogenomics of non-model organisms. Newly sequenced reference genomes from this understudied clade will be thoroughly purged of contaminants considering read coverage, GC content, and BLAST hits. Gene models from decontaminated genomes will be compared to potentially contaminated transcriptomes with OrthoFinder and PhyloPyPruner and erroneously inferred "paralogs" best explained by contamination will be purged using our novel software. Utilizing both supertree and supermatrix approaches we aim to further resolve relationships within Lophotrochozoa.

P14-2 Robin, AN*; Lessig, E; Frausto, C; University of California, Los Angeles , University of Texas at Austin ; *robina@ucla.edu*
Increasing diversity through community college student engagement: A student run organization model
Just under half of all undergraduate students in the United States are enrolled in community college. Yet, the rate at which students that start college at 2-year institutions matriculate into STEM-related graduate programs is low. Maintained academic persistence and lack of equal opportunity to engage with research contribute to this disparity. Further, the diversity of student bodies on community college campuses exceeds that of most four-year institutions. Therefore, to increase diversity in STEM it is critical to include community college students. The Community College Field Biology Alliance is a student-run organization that provides community college students with the opportunity to conduct field research. We also demystify the graduate school admissions process and make the pursuit of a STEM career a tangible reality for our students. Over the 2 past years, we have worked with 18 students to design, enact, and present original research projects. The success of our program is a demonstration that concerted efforts to increase diversity and persistence in STEM can be implemented by individuals at all levels of academia.

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P23-3 Roden, JW*; Bidwell, JR; East Tennessee State University; *rodenjw@etsu.edu*

The effects of impoundments on downstream food availability in relation to freshwater mussel growth and condition

The renowned freshwater mussel diversity of the southeastern United States has seen significant declines over the past century due to pollution and habitat degradation. This study investigated the influences of altered river flow regime due to hydroelectric dams on food quality for freshwater mussels. Chlorophyll$_a$ and organic content of seston was measured monthly at four sites on the Pigeon River in Tennessee and compared with four sites on the Tennessee sections of the Nolichucky River. The Pigeon River is regulated by a hydroelectric dam that causes significant daily variations in flow, while the Nolichucky River is not regulated, but features a defunct hydroelectric dam that creates an impoundment on the river. Growth and total body glycogen content of Pocketbook mussels, *Lampsilis ovata*, were assessed at one site downstream from the active dam on the Pigeon River and the impoundment on the Nolichucky. From July thru December 2019, chlorophyll$_a$ concentrations in seston and growth and total body glycogen of *L. ovata* from the Nolichucky River were significantly greater than those on the Pigeon River, and flow rate was significantly correlated with chlorophyll$_a$ and organic matter concentrations. While these results may suggest that frequent regulation on the Pigeon River may be reducing food availability, they warrant investigation of potentially favorable conditions for mussel populations occurring downstream from inactive dams. In July 2020, rainbow mussels, *Villosa iris*, were translocated to the same sites on the Pigeon and Nolichucky Rivers and to an additional site above Nolichucky Dam to investigate differences in mussel growth and condition above and below the impoundment and to verify results from the previous season with a new native mussel species.

P3-5 Rodriguez, C*; Sayegh, N; Chamanlal, A; Maia, A; Rhode Island College, Providence, RI; *crodriguez_3018@email.ric.edu*

A nerve roadmap to the bluegill spiny dorsal fin

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The spiny dorsal fin is essential in recovering fish stability after perturbations. We have previously shown that loss of sensory information or motor control causes disruptions in coordinated movement and delays recovery of stability. To understand control input to fin motion, specimens of our model species, the bluegill *Lepomis macrochirus*, were examined to evaluate afferent and efferent fin innervation. To identify the sensory array and the associated ascending innervation as well as the descending motor neurons, we used various histological techniques including whole clear and staining, whole fin staining with Luxol Fast Blue, Cresyl Violet, Sudan Black B, serial sectioning and immunohistochemistry with anti-acetylated tubulin. The best staining protocol for macro identification of nerves was Cresyl Violet, which stained the Nissl bodies of neurons purple and enable mapping of the motor nerves. We found branching innervation of the descending tracks into the erector muscles of the spiny dorsal fins. Results from immunostaining of dorsal fin rays 2 and 4 and the surrounding muscle showed heavy innervation suggesting fine motor control. Anti-acetylated tubulin staining revealed sensory neurons present in the fin rays, as well as on the fin web of the spiny dorsal fin, similar to what has been reported in pectoral and soft dorsal fins in other fish species. Motor innervation was denser closer to the joint at the base of each spine, which was surprisingly well developed. Information on the delivery of motor control and sensory feedback will help propose a mechanism for how spiny dorsal fin deployment is fine tuned. By having a better understanding of simple connectomes, we can develop prototypes for prosthetic devices that modulate motor function with local sensory input.

P21-10 Romero, JA*; Wainwright, P; Stuart, H; UC Berkeley, UC Davis; *romeroja@berkeley.edu*

Experimentally decoding the forces of butterflyfish on anchored prey

Coral-feeding fishes utilize intricate jaw structures and motion profiles for specialized substrate feeding. Additionally, they are capable of employing suction feeding or whole-body maneuvers when interacting with prey. Prior studies with live corallivores have focused primarily on video observation, and have not measured external biting forces in multiple axes. To characterize the

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interactive behaviors of such fishes, we study the sunburst butterflyfish (*Chaetodon kleinii*), a facultative corallivore that browses corals to remove polyps with minimal damage to the skeleton (Rotjan, Lewis, *MEPS*, 2008). We present an experimental system to characterize the bite of these corallivores by synchronously capturing high speed video (2 kHz framerate) and force/torque data in 6 axes (20 kHz sampling). The apparatus is designed such that an appropriate coral substrate or other food source can be rigidly mounted to the force transducer and then submerged for feeding measurements. We seek to explore both dorsal and lateral views of feeding. Preliminary video data shows that *C. kleinii*, as expected, extend both premaxilla and mandible prior to biting, and incorporate whole-body movements during substrate biting. This new experimental method yields more holistic analysis of butterflyfish biting mechanics through a timeseries pairing of motion and force in three-dimensional space. This opens the possibility of disambiguating hydrodynamic and inertial forces or examining the presence of brushing and suction actions during benthic feeding. Initial data shows peak forces on the order of 0.5 N, predominantly in the anterior direction, and biting events on the order of 100 ms. This work is projected to motivate design and control principles for biophysical modeling of corallivory and future application to bio-inspired coral sampling.

P33-11 Ross, SA*; Wakeling, JM; Simon Fraser University, Burnaby, BC; *saross@sfu.ca*

The effects of muscle tissue inertia and series elasticity on the metabolic cost and efficiency of contraction

Tissue inertia is rarely considered in our understanding of skeletal muscle behaviour. Studies have shown that larger muscles perform less mass-specific mechanical work during cyclic contractions due to their greater inertial mass; however, it is not known how this greater mass alters the metabolic cost and efficiency of contraction. In this study we examined the effects of tissue inertia on muscle metabolic cost and efficiency during cyclic contractions. To accomplish this, we simulated work-loop contraction cycles of a mass-enhanced Hill-type muscle model with bursts of excitation timed to sinusoidal muscle length changes. We additionally explored how the behaviour of a tendon alters the

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relationship between tissue inertia and muscle and muscle-tendon unit mass-specific mechanical work, metabolic cost, and efficiency per cycle by adding a tendon of varying stiffness in series with the muscle model. We found that larger muscles with greater tissue inertia are less efficient than smaller muscles, primarily due to their lower mass-specific mechanical work output. We also found that accounting for a tendon decreased the mass-specific work and efficiency penalty of larger muscles, but this depended on the stiffness of the in-series tendon and the timing of the muscle excitation relative to the sinusoidal length changes. The results of this study highlight the importance of accounting for muscle tissue inertia when predicting whole muscle and muscle-tendon unit behaviour.

P33-2 Ross, CD*; Meyers, RA; Weber State University, Ogden, UT; *rmeyers@weber.edu*

Anatomy and muscle fiber types of kangaroo rat hindlimb muscles

Kangaroo rats (*Dipodomys* spp.) use a specialized bipedal hopping locomotion like that of kangaroos. In contrast to kangaroos that have elastic tendons capable of storing energy, kangaroo rats have inelastic tendons that are unable to store large amounts of energy. Thus, it is the musculature of the ankle joint that provides the greatest power contribution to hopping. Skeletal muscle can be divided into slow twitch (type I) and fast twitch (type II) fibers. Fast fibers are found in higher percentages in muscles that perform quick, dynamic movements, whereas slow fibers are found in higher proportions in muscles that perform slow, endurant movements. Using fiber type-specific antibodies, we identified four pure (type I, IIA, IIB, and IIX) and two hybrid fiber types (type I/IIA and IIA/IIX) in six hindlimb muscles (Mm. soleus, plantaris, gastrocnemius, tibialis anterior & extensor digitorum longus) from three kangaroo rats (*Dipodomys merriami*). Soleus was dominated by type I fibers, which are well-known for having a postural role. The other hindlimb muscles studied were dominated by type IIB fibers, which are known to be best suited for rapid and explosive movements. The high percentage of type IIB fibers found in these muscles can be related to the explosive hopping behavior that the kangaroo rat exhibits in order to escape predators, such as rattlesnakes. Oxidative type IIA and type IIX fibers were found at

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moderate percentages and are suggested to maintain continual saltatory locomotion. Two hybrid fibers (type I/IIA and IIA/IIX) were observed in minimal quantities suggesting that there is limited muscle fiber transformation occurring. By having a heterogeneous muscle fiber type composition, the kangaroo rat can maximize muscle function to display a broad range of force generation and fatigue resistance. properties.

P31-6 Rudzki, EN*; Antonson, ND; Louder, MIM; Schelsky, WM; Hauber, ME; Kohl, KD; Univ. Pittsburgh, Univ. Illinois Urbana-Champaign; *elr82@pitt.edu*

Phylogeny does not always rule the roost: High similarity in the fecal microbiome of obligate brood parasitic nestlings and their host nestmates

In general, animal species harbor distinct microbiomes and the similarities of these communities mirror host phylogeny: an eco-evolutionary pattern known as phylosymbiosis. However, the ubiquity and strength of phylosymbiosis in avian microbiomes are weak and remain poorly understood. Avian brood parasites provide unique opportunities to investigate the roles of genetics vs. environment as both species' nestlings are raised in the same nest, on the same diet, and by the same parents. We utilized a model of two passerines (from order Passeriformes), the obligately interspecific brood parasite Brown-headed Cowbird *Molothrus ater* (BHCO) and one of its hosts, the Prothonotary Warbler *Protonotaria citrea* (PROW), to investigate how species identity and parasitism affects the gut host-associated bacterial microbiome (HAMB) of the developing nestlings. We sampled the fecal microbiome of wild BHCO nestlings and PROW nestlings from both parasitized and unparasitized nests. While we were able to detect significant influences of sampling locality, we found that the presence or absence of a brood parasite nestling did not significantly alter the developing HABM of the PROW nestlings. Further, the fecal HAMB of BHCO and PROW were indistinguishable from one another. Our findings run contrary to those found in other brood parasite systems where hosts and parasites represented different taxonomic orders. Thus, rearing environment may be especially important in determining the microbiome of brood parasite nestlings, and genetics are not strongly influencing the parasite HAMB at this early stage in life.

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P18-5 Sadowska, J*; Gębczyński, AK; Lewoc , M; Konarzewski, M; Department of Evolutionary and Physiological Ecology, Faculty of Biology, University of Białystok,
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Not that hot after all: no limits to heat dissipation in lactating mice selected for high or low BMR

Heat dissipation has been suggested as a limit to sustained metabolic effort, e.g. during lactation, when overheating is a possible risk. We tested this hypothesis using mice artificially selected for either high or low BMR that also differed with respect to parental effort. We used fixed size cross-fostered families and recorded litter mass daily until the 14th day of lactation. Midway through the experiment (day 8) half of the mothers from each group had fur from the dorsal body surface removed to increase their thermal conductance and facilitate heat dissipation. Our results showed that neither high nor low BMR mouse lines benefited from increasing their thermal conductance at peak lactation. On the contrary, growth of the litters reared by the low BMR females was compromised. Thus, our results do not support the heat dissipation limitation hypothesis.

P29-6 Sajadi, F*; Paluzzi, JP; York University, Toronto, ON; *farwa@my.yorku.ca*

How does CAPA inhibit fluid secretion in the female Aedes aegypti mosquito: cellular mechanism and signaling pathway

Female *Aedes aegypti* mosquitoes face the challenge of excess water and ion intake after a blood meal. To cope with this, female *A. aegypti* have a highly active excretory system that includes the Malpighian tubules (MTs), which are under rigorous control by several neuroendocrine factors to regulate transepithelial movement of ions and osmotically-obliged water. CAPA neuropeptides, produced in the CNS are evolutionarily related to the vertebrate neuromedinU peptides. While extensive studies have investigated the effects of CAPA peptides on diuresis, the role of CAPA in adult *A. aegypti* remains unclear. Given that CAPA receptor transcript was localized to the principal cells of the MTs, the objectives of the study were to identify the components of the signaling cascade

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leading to CAPA-induced inhibition of fluid secretion. Through fluid secretion assays, it was shown that CAPA inhibits fluid secretion by tubules stimulated with specific diuretics, 5HT and DH_{31}, whilst maintaining the relative Na^+ and K^+ transport in the MTs. Interestingly, CAPA was found to not influence CRF-stimulated secretion in the tubules. Pharmacological inhibition of PKG/NOS signalling abolishes the anti-diuretic activity of CAPA, confirming its role in the CAPA signaling pathway. Furthermore, MTs treated with bafilomycin, a proton pump inhibitor, was found to inhibit fluid secretion stimulated by 5HT and DH_{31}, while having no inhibitory action on CRF-stimulated MTs. Additionally, alkalization of the secreted fluid in response to CAPA suggests inhibition of the proton pump, which may lead to constrained cation entry across the apical membrane of the MTs. Further understanding the role of each specific hormone family, including both diuretic and anti-diuretic factors, will help resolve this complex regulatory network.

P3-1 Santa Rita, ZS*; Gray, JR; University of Saskatchewan, Saskatoon, SK; *zas791@usask.ca*

A locust visual neuron responds to object trajectory changes in the vertical plane

Animals respond to numerous biologically relevant environmental stimuli by performing various behaviours. Organisms such as locusts swarm during unfavorable conditions in complex, dynamic visual environments that requires collision detection systems to successfully orient themselves amongst stationary objects and conspecifics to avoid threats such as an approaching predator. Locusts (*Locusta migratoria*) and their visual motion-detection pathway, comprised of the lobula giant movement detector (LGMD) and the descending contralateral movement detector (DCMD), responds selectively to objects approaching on a direct collision course. We presented the locusts with biologically relevant stimuli of 3D objects with trajectory changes along the vertical plane. We have found that stimulus that change in trajectory in the vertical plane is consistent with objects that change in trajectory along the horizontal plane. Data shows that there is a slight delay in firing in the motion-detection pathway after the stimulus changes trajectory. This allows us to infer that there is a generalized

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system within the locust to recognize approaching objects regardless of its origin. Although insects may have less complex neural systems than mammals they are highly capable of processing elaborate visual cues to navigate and orient themselves in their natural environment.

P39-8 Schaefer, JL*; Ayers, D; University of California Davis; *jlschaefer@ucdavis.edu*

A conceptual framework for phenological mismatches: interspecific interactions modulate consumer-resource mismatches under environmental change

Animals and plants use cue response systems to ensure that important life history activities, such as reproduction, are carried out during temporal windows of optimal environmental and biotic conditions. Such precise timing of life cycle activities can be adaptive, but the effects of climate change may render this approach detrimental to the fitness of individuals and persistence of populations. For example, climate change can generate mismatches, where an organism's seasonal life cycle activities (phenology) become temporally misaligned with the availability of its key resources. Here we identify three categories of factors that interact to determine whether, and to what extent, consumer organisms will mismatch with the resources they rely on: environmental factors, organismal factors, and interspecific interactions. *Environmental factors* include the types and stability of abiotic cues (e.g., day length, temperature, rainfall) that animals use to synchronize life history activities with resource availability. *Organismal factors*, such as physiological tolerances and degree of phenotypic flexibility, affect how a focal consumer will respond to changes in its environment with regard to timing. Finally, organisms can be characterized by features of their *interspecific interactions* that affect their ability to remain temporally synchronized with resources, including the breadth of resources utilized, position in the trophic web, type of interaction (e.g., mutualism vs. parasitism), and evolutionary history of interactions. We present a framework that links these three types of factors with two possible phenological outcomes: timing match or mismatch.

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P23-2 Schoenfeldt, A*; Stack Whitney, K; Rochester Institute of Technology, Rochester, NY; *axs9530@rit.edu*

Assessing road traffic and roadside mowing levels on pollinator habitat quality in highway roadsides

Roadside rights of way (ROWs), the grassy areas that are parallel to roads, are potential habitats for pollinating insect conservation efforts as more natural habitats are lost. However, roadside ROWs are also highly disturbed areas, due to the effects of on-road traffic and roadside management practices, like mowing. Reduced mowing may result in more quality habitat through increased floral presence for habitat and foraging. Yet previous research on mowing, pollinators, and traffic has been limited in scope. Our objective was to examine if changes in road traffic and roadside mowing are associated with changes in pollinating insect habitat quality in highway roadsides at the landscape scale, large range of traffic volume, and across multiple years. We measured pollinating insect habitat quality in 30 highway ROWs across New York State in 2019 and 2020. The sites were categorized into either reduced or control mowing treatments as well as into low, medium, and high traffic levels. Control mowing areas received the current mowing schedule, and reduced mowing areas were not mowed in 2019 and were mowed in 2020 only after a plant-killing frost. We used the most recent annualized average traffic data to categorize sites as low (0-4000 cars per day), medium (4001-10000), or high (10001-55000) traffic. We had a total of 176 sampling locations across all treatments. At each, we counted wild bee and honey bee abundance on flowers across a 100 foot by 3 foot transect, repeated twice each year. We assessed the association of traffic level and mowing frequency with bee abundance using linear mixed-effects models. Our results will inform ROW management practices and roadside pollinator conservation initiatives.

P33-5 Schwartz, RM*; Cost, IN; Albright College; *Robert.Schwartz001@albright.edu*

Getting a grasp on the avian tendon locking mechanism

Birds make use of their lower limbs for functions such as grasping, climbing, wading, digging, nest building along with many other

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actions. The tendon-locking mechanism (TLM) underlying the closing of digits of bird feet is essential for aspects of the avian lifestyle. A number of studies have previously investigated the mechanics of the TLM across multiples species. This project describes the forces underlying the TLM mechanism. We use properties of the flexor muscles of the leg used for grasping behaviors in related avian species, Red-tailed hawk (*Buteo jamaicensis*) and Cooper's hawk (*Accipiter cooperii*) to address this mechanism. Using traditional dissection and muscle evaluation techniques, flexor muscles of the left leg were collected to estimate the physiological cross-sectional area (PCSA) and muscle force in Newtons. Muscles were removed at proximal and distal attachments. Pennation angles and the mass for each muscle were measured before muscles were immersed in HNO_3 to facilitate muscle fiber separation. Many fibers from each muscle were carefully arranged and photographed for data collection. Mean muscle fiber length, pennation angle, and PCSA were used to calculate forces muscles are capable of contributing to the TLM. We found that the larger Red-tailed hawk's muscles had greater force outputs when compared to the muscles of the smaller Cooper's hawk. A wider sampling of species is necessary in to gain a better understanding of how the forces contributing to the TLM affect the lifestyle of various species of birds.

P28-8 Schwartz, ST*; Alfaro, ME; University of California, Los Angeles; *shawnschwartz@ucla.edu*

Sashimi: Automatic high-throughput pipeline for organismal image segmentation using deep learning

Deep learning, a branch of machine learning, can serve as a powerful toolkit for studies in ecology and evolutionary biology. Image segmentation is one powerful application of deep learning that has enormous potential for high-throughput phenoscaping in biological studies. As large-scale color pattern analyses across the tree of life become increasingly popular, the need for standardized, high fidelity image sets of organisms becomes essential. One rate-limiting step when preprocessing images of specimens for color pattern analysis is to mask out the background pixels of the image to prevent those pixels from influencing color pattern geometry statistics. Previous studies have relied on manual

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labor and image editing software to meticulously mask out background pixels; however, this method is relatively slow and lacks reliable consistency when implemented at larger scales with more variability in worker quality. Furthermore, simply using deep learning to conduct image segmentation on taxa is not possible when taking the most commonly used regional convolutional neural network (R-CNN) models at face value, as these deep learning models have been trained on a very small fraction of biodiversity across the tree of life. We therefore custom trained a model to automatically perform high-throughput image segmentation on a heavily underrepresented group in the model space: coral reef fishes. We also present sashimi, a web-based toolkit for manually segmenting images and creating new training datasets for taxa, and a Python-based automated pipeline to carry out background pixel segmentation on any group for which a new model has been trained. We also show that our custom trained fish segmentation model generates cropped images well suited for popular downstream color pattern analysis workflows.

P38-5 Seleb, BR*; Bhamla, MS; Georgia Institute of Technology, Atlanta, GA; *bseleb3@gatech.edu*

A modular, programmable, open-source camera trap platform

The observation of animals in their native habitats offers the opportunity to collect unique information on the abilities with which they accomplish ecologically relevant tasks. However, this kind of study poses challenges related to species abundance, time requirements, and the absence of typical laboratory resources like lighting and power. To meet these challenges, field biologists have turned to camera traps that can remotely record animal behavior and remain battery-powered for long periods of time. Despite their increased use, many researchers indicate that camera traps lack in their effectiveness as precision research tools. This is especially true of research endeavors that have specific data requirements, such as highspeed video, as well as endeavors focused on species other than the large mammals for which commercial camera traps were designed. In this ongoing study, we performed an in-depth review of previous developer's attempts to expand the capabilities of the conventional camera trap platform. Having identified obstacles presented by previous attempts and by using collected user

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information to develop design specifications, we propose a fundamentally new, open-source camera trap platform that offers unprecedented modularity and programmability. By giving the users the ability to easily swap between different sensors, lights, and cameras, the new camera trap platform can become a precision tool for every study. Additionally, with the input of several sensors and the capability to perform edge-processing, like pixel-change detection, research capabilities can be expanded even further. We look forward to discussing this project with members of the SICB community to learn about their specific needs as well as to collaborate with potential beta testers!

P9-10 Seman, B*; Ryan, JF; Santagata, S; Long Island University, Brookville, NY, University of Florida, Gainesville; *brooke.seman@my.liu.edu*

Temperature effects on metabolic enzymes from Antarctic and sub-tropical marine bryozoans

Metabolic enzymes are often the targets of selection exhibiting various molecular features related to temperature adaptations. Our group assembled transcriptomic datasets from closely related species of Antarctic and sub-tropical marine invertebrates called bryozoans testing for genes under positive selection using different kinds of bioinformatic tests. Based on these results we compiled a list of genes involved in the metabolic processes of the bryozoans to test for the effects of varying temperatures on their functionality, specifically those involved in the mitochondrial Citric Acid Cycle. With the use of molecular and recombinant expression techniques our lab synthesized orthologous forms of isocitrate dehydrogenase-2 (IDH-2) from both Antarctic and sub-tropical bryozoan species. Using different IDH-2 forms we tested the effect of temperature and substrate concentration on the enzymatic reaction to calculate the maximum reaction rate (V_{max}) and the Michaelis-Menten constant (K_m) for these enzymes. Our preliminary results indicate that IDH-2 forms from both the warm- and cold-water species function within a wide range of temperatures. IDH-2 forms from Antarctic species may be more cold-tolerant, whereas the activity of IDH-2 forms from warm-water species are more stable at higher temperatures. Our collaborative research group is currently expanding the taxonomic sampling of our

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transcriptomic datasets leading to more robust tests of positive selection and further experimental tests of potential temperature adaptations among metabolic enzymes. Going forward, these data will shed new insights on the kinds of molecular signatures typical of potential adaptions of genes from Antarctic taxa.

P23-7 Sereewit, A*; Onthank, K; Walla Walla University; *sereewit@hotmail.com*

Do octopuses change RNA editing patterns in response to ocean acidification?

Ocean acidification is the increase in ocean acidity due to increased atmospheric CO_2 produced by human activities. As ocean acidity is predicted to more than double by 2100, organisms that can easily adapt may have an advantage when dealing with such rapid environmental changes. One method of adaptation is RNA editing. RNA editing is a posttranscriptional modification of the RNA molecules generally accomplished by adenosine deaminase acting on RNA. RNA editing exists in many organisms, but RNA edits are substantially more common in cephalopods, especially nonsynonymous edits. In this study we looked for changes in RNA editing levels in gill tissue of *Octopus rubescens* exposed to elevated CO_2. Three octopuses were kept in closed aquaria with an average pCO_2 of 1517 ± 254 μatm, and the other three octopuses kept in closed aquaria with an average pCO_2 735 ± 47 μatm for two weeks. Then their gill tissues were collected for mRNA extraction and sequencing. Editing sites were found by aligning mRNA and gDNA of individual *Octopus rubescens* to their consensus transcriptome and finding locations where there are mismatches between the mRNA reads and the transcriptome as well as between the gDNA reads and the transcriptome. Differential edits were verified using poisoned primer extension assays.

P20-3 Shankar, A*; Cisneros, INH; Thompson, S; Graham, CH; Powers, DR; Cornell University Ithaca NY and Stony Brook University, Stony Brook NY, George Fox University, Newberg OR, Swiss Federal Research Institute WSL, Birmensdorf Switzerland and Stony Brook University, Stony Brook NY; *nushiamme@gmail.com*

A spectrum of sleep, shallow torpor, and deep torpor in hummingbirds

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Animals in torpor drop their body temperature and metabolism, slowing down a suite of physiological processes, as low as their physiology and the ambient temperatures will allow. Some species can drop their body temperatures by 23-34° C, entering deep torpor, while many others have relatively high body temperatures while in shallow torpor (e.g., 3-10° C below normothermy). Studies on mammals show that potential costs of using deep torpor include increased predation risk, inhibited immune function, and a lack of restorative sleep. Therefore even for species that are capable of deep torpor, facultatively adopting a shallower form of torpor might sometimes be a better strategy for balancing energy savings against these potential costs of deep torpor. However, little empirical evidence exists for a spectrum between avian deep and shallow torpor within species. We explored whether hummingbirds, which are known to use deep torpor frequently, are also capable of shallow torpor, with intermediate reductions in their body temperature and metabolic rate. We took infrared videos of three hummingbird species under natural temperature and light cycles, and found that they all used both deep and shallow torpor, often on the same night. The species varied in their use of shallow torpor from averages of 5% of the night to 35% of the night. The presence of this torpor spectrum indicates that some birds have very fine control of their sleep and torpid metabolism. I will next be using transcriptomics to investigate the physiological differences between sleep and shallow and deep torpor.

P1-5 Shao, HS*; Suzuki, Y; Wellesley College, Wellesley, MA; *hshao@wellesley.edu*

Mathematical modeling of growth in insects

Understanding the regulation of body size has important consequences for our understanding of life history trade offs, reproductive fitness and survivability. Recent studies in insects have begun to identify critical regulators of size. Insects undergoing complete metamorphosis grow in size as larvae but stop feeding and begin metamorphosis once a particular size has been reached. Since growth ceases as they approach metamorphosis, the growth rate and duration of an insect's larval stages determines its adult body size. The complex process of size control involves multiple factors including nutritional availability, and

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physiological and genetic regulators. Previous research has described the cascade of endocrine events that cause larvae to cease growth. Although the key hormones involved in this process have been identified, the extent to which the mechanisms of growth are conserved across species remains unknown. Our study aims to develop a mathematical model to illustrate the roles of various factors on the final body size of insects across species. We utilize differential equations to reflect the relationships between growth regulators and compare the model to growth regulation in several insect species, including the tobacco hornworm, *Manduca sexta*, and the fruit fly, *Drosophila melanogaster*. The model depicts the production and suppression of these regulators during larval growth to visualize different scenarios that affect growth rates and growth cessation. By manipulating a variety of constants that can mimic normal and mutant insects of different species, the model predicts changes in metamorphic timing and resulting adult body size. Through our model, we seek to present a more comprehensive image of size determination and illuminate missing puzzle pieces in our understanding of growth regulation.

P28-5 Sharma, SN*; Sharma, SN; Young, MA; Hahn, TP; Franklin High School, Carle Illinois College of Medicine, Univ of Illinois, Urbana-Champaign, Cornell Univ, Univ of California Davis; *shaynairsharma@gmail.com*

Acoustically distinct contact calls of two subspecies of a New World warbler, Setophaga coronata

The myrtle and Audubon's warblers are genetically and morphologically distinct subspecies of the yellow-rumped warbler (*Setophaga coronata*) that share a geographical hybrid zone. Although bird watchers know that these taxa are separable by ear based on "chip" call, there has been no systematic examination of the nature of this call variation. We screened 203 recordings of myrtle and 134 recordings of Audubon's warblers obtained from Xeno-Canto, and selected 10 high-quality recordings from each subspecies for analysis. We then performed waveform and spectrogram analyses to identify quantitative features of selected exemplar calls using Raven Lite. "Chip" calls of the two subspecies were distinct in starting frequency, frequency range, duration, and shape. Specifically, Audubon's calls began at an average frequency of 3565

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Hz, higher than the myrtle call at 3313 Hz. The total duration was longer for Audubon's calls (0.0272 seconds) than for myrtle (0.0180 seconds). At 0.0091 seconds into the call, myrtle warblers attained an average peak frequency of 6278 Hz and then abruptly dropped in pitch, while Audubon's frequency increased throughout the call to a peak of 5870 Hz at the end. The frequency range was thus greater for myrtle (3313-6278 Hz) than for Audubon's warblers (3565-5870 Hz), and myrtle calls rose and then fell in pitch, whereas Audubon's calls only rose. This study provides a basis for examination of geographic vocal variation across the range of each taxon, and our approach should be considered when looking for hybrid individuals, which may produce intergrade calls. Similar analyses of simple, innate calls of other species with multiple subspecies may prove fruitful.

P33-4 Shehaj, A*; Rimkus, B; Putra, C; Konow, N; University of Massachusetts Lowell; *andrea_shehaj@student.uml.edu*

Effect of protein origin on skeletal muscle physiological performance

Consumption of protein supplements can induce muscle hypertrophy when combined with exercise, but the isolated effects of differing protein diets on muscle mechanical performance remain poorly understood. We sought to determine the effects of protein origin (animal- vs plant-based) on muscle mechanical properties (mass-specific force, and peak contraction speed). Mouse cohorts were fed diets with protein derived from casein (N = 7), whey (N= 5), and pea (N=4). Dietary amino acid content was carefully balanced to ensure equivalent protein synthesis. After a minimum of a 6-week dietary intervention, we performed muscle ergometry to measure force-length-velocity relationships from two muscles: soleus (SOL), a plantarflexor with a mixed fiber type composition in near parallel-fibered configuration, and tibialis anterior (TA), a fast-twitch, relatively pennate-fibered dorsiflexor. Casein outperformed both whey and pea in terms of muscle-mass specific force, while the inverse was true for peak contraction speed, in accordance with the force-velocity trade-off. TA from casein-fed mice produced mass-specific forces of 23.2 ± 7.9 compared to 18.4 ± 4.2 and 15.9 ± 0.4 N/g for whey and pea respectively. Peak contraction speed of TA (in optimal lengths, Lo/sec) were 6.4 ± 1.7, 5.9 ± 1.6, and 6.5

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± 0.7 Lo/sec for casein, whey, and pea respectively. These results may inform advocacy for dietary protein sourcing, especially casein, a slow-absorbing protein source.

P38-3 Shu, Y*; Sirvid, PJ; Boyer, SL; Macalester College, Museum of New Zealand Te Papa Tongarewa; *yshu@macalester.edu*

Geographic inventory of New Zealand's mite harvestmen (Arachnida, Opiliones, Cyphophthalmi)

Mite harvestmen (Cyphophthalmi) are excellent models for studying historical biogeography due to their ancient age and limited dispersal. These tiny arachnids occur throughout New Zealand's North and South Islands as narrow range endemics. Occurrence data, the recording of a species at a specific location and date, has been collected on New Zealand's mite harvestmen for a century now. These records are held by many museums, but have never been combined in one place. Having a comprehensive database facilitates the sharing of knowledge through easier access to collection records. Records from fourteen museums were merged into a single spreadsheet, with the format derived from Global Biodiversity Information Facility (GBIF) standards. In total, we compiled data for 1115 collections, comprising over 5000 specimens. Going forward, this database will be used to illuminate biogeographic patterns, such as regional comparisons of species richness across New Zealand.

P30-6 Sibiskie, CL*; Krans, JL; Western New England University, Springfield, MA; *cs359111@wne.edu*

Contributions of the titin ortholog, sallimus, to stress strain relationships in Drosophila larval body wall: work loop analysis of sls knockdown and actomyosin interruption

We are investigating the material properties of *Drosophila* body wall muscle and are particularly interested in contributions from giant sarcomere associated proteins (gSAPs) such as the titin ortholog, sallimus. Our tethering hypothesis suggests that gSAPs contribute substantially to work loop hysteresis *after* motor neuronal activity. We used two techniques to test this: (1) the previously described RNAi knockdown of the sallimus gene in *D. mel*, (2) the myosin inhibitor para-amino blebbistatin to interrupt

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actomyosin cycling. Stress was measured in response to cyclical length change (strain) under three physiologic conditions: (1) passive muscle [epoch 1], (2) five seconds of 15 pps motor activation [epoch 2], and (3) 15 seconds following the cessation of stimulation [epoch 3]. Much work remains, but initial results show that variation in stress recorded during epoch 2 increased in animals with reduced sls expression (RNAi), which is consistent with the tethering hypothesis of gSAP action. Moreover, variation in the decay of stress after muscle activation was greatest in sls RNAi animals. We continue to investigate the tethering hypothesis using the myosin inhibitor, para-amino blebbistatin and predict that it's application will *not* eliminate the increased variability of stress associated with sls knockdown. Such findings would be consistent with the hypothesis that sls can continue to modulate stress after cessation of stimulation or perhaps in the absence of actomyosin cycling.

P4-1 Sierra, MM*; Rummel, AD; Kobayashi, T; Swartz, SM; Brown University; *melissa_sierra@brown.edu*

Sensing in bat wings: A comparative analysis of sensory hair density in bat wing membranes

Bats are agile flyers and this capability is made possible by both sensory and musculoskeletal adaptations, including echolocation, their muscle-actuated, many-jointed wings, and their specialized wing membrane. Previous studies have noted the presence of sensory hairs on the membranes of bat wings and explored their function, suggesting these may act as airflow sensors. However, research on the distribution of these hairs across wing regions and bat species is limited. In this study, we aim to address these gaps through comparative analysis of sensory hair distribution on the wings seventeen bat species from ten families, representing much of extant bat diversity. We measured hair area density (hairs per cm^2) from high-resolution auto-fluorescence micrographic images by counting sensory hairs in specific regions of the wing, identified by anatomical landmarks. We performed phylogenetic and non-phylogenetic statistical analyses to determine if sensory hair density differs among selected wing regions and among species, and to explore potential correlations between sensory hair distribution and ecological parameters. We found that hair density generally

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decreased from proximal to distal along the wing. Forearm length, a proxy for body size, negatively correlated with hair density, though this pattern was accounted for by body size-phylogeny covariation. Species in the family Molossidae (*Tadarida brasiliensis* and *Molossus rufus*) differed greatly from others, and displayed much higher hair density in the proximal region of the wing than other species in this study. Ecological factors such as feeding guild did not relate to hair distribution on the wing after phylogenetic correction, suggesting that phylogeny is the primary driver of variation in hair density among species in our sample.

P12-9 Simmons, MJ; Elcock, J; Evans, K; Farina, SC*; Howard University, Washington DC, University of Washington and Howard University, Washington DC, Rice University, Houston, TX; *stacy.farina@howard.edu*

Ventilatory shunting and its relationship to urohyal shape in flatfishes

Flatfishes (Pleuronectiformes) are characterized by their asymmetrical skulls, with both eyes on one side of the head. Flatfishes lay with their "blind" side facing the sediment and "eyed" side facing upward. The urohyal is an ossified tendon of the sternohyoideus. In flatfishes, this bone forms a channel between the eyed and blind gill chamber for water to flow through. Micro-CT scans of 56 flatfish species were used to quantify the morphological variation of the urohyal. We created a phylomorphospace that illustrates urohyal shape diversity. We then recorded gill chamber ventilatory pressures from five flatfish species. We examined the relationship between asymmetrical ventilatory pressures, urohyal shape, and ecology. Asymmetrical ventilatory pressures were observed in each species during above sand breathing, burial, and below sand breathing. Degree of asymmetry was not proportional to variations in urohyal shape. We expected to see a higher degree of asymmetry in species whose urohyals formed larger canals for shunting. This data shows us that the degree of asymmetry in ventilatory pressure is not influenced by the shape of the urohyal.

P26-2 Singh, P*; Brar, G; Scrapper, B; Floden, M; Rinehart, JP;

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Bowsher, JH; North Dakota State University, USDA-ARS Fargo; *preetpal.singh@ndsu.edu*

Investigating the impacts of temperature, photoperiod, and population density on diapause incidence in the alfalfa leafcutting bee, Megachile rotundata

The alfalfa leafcutting bee, a solitary pollinator for alfalfa seed production, undergoes facultative diapause in the prepupal stage. Most early season progeny complete development to produce a second generation whereas most late season progeny diapause as prepupae. The cues regulating diapause incidence are not completely understood. To determine the effects of temperature, photoperiod, and population density on diapause incidence, we designed and installed six replicate nest boxes in alfalfa fields near Fargo, ND. We expected that there would be a temperature dependent response of diapause incidence in which larvae experiencing temperature units above a threshold will diapause and the flip in the diapause incidence would occur in response to a decreasing rate of daylength. Similar to our previous results, diapause incidence within a nested cohort was strongly influenced by the conditions experienced by the mother bee, we expected that increased population density would increase diapause incidence. Understanding the cues regulating the diapause incidence will help in sustainable bee management.

P24-2 Smaga, CR*; Allender, MC; Jiménez, FA; Southern Illinois University, Carbondale, IL, University of Illinois, Urbana, Illinois ; *christopher.smaga@uga.edu*

Estimation of prevalence and qPCR copy number of Ophidiomyces ophiodiicola and Snake Fungal Disease in a snake community in southern Illinois, with notes on detection methods

Snake Fungal Disease (SFD), also known as Ophidiomycosis, is an emerging pathogen caused by *Ophidiomyces ophiodiicola*, known to affect a wide range of snake species. Recent establishment of reliable detection methods has allowed monitoring of populations infected with the fungus. However, the full impacts are not well-known, and much of the work on wild snakes has focused on specific populations of a few species, while community wide surveys are few. Through the use of qPCR, we document prevalence of clinical signs of SFD and fungal copy number of *O.o.* in a snake community in

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southern Illinois. We sampled 56 snakes of 12 species and found that both clinical signs and *O.o.* are prevalent at the site. Using data from facial and dorsal swabs, we conclude that clinical signs may be predictive of fungal copy number, and there is no significant difference between swab types. We hope this work will improve the detection and knowledge of SFD in wild snakes.

P11-3 Smith, SK*; Young, VKH; Saint Mary's College, Notre Dame IN; *ssmith02@saintmarys.edu*

Tail length in fox squirrels (Sciurus niger) at Saint Mary's College

The post-anal tail is a key feature in vertebrates that plays a fundamental functional role. In arboreal taxa, tails aid in balance, stability, and reorientation. The enhanced maneuverability provided by the tail is especially important for arboreal locomotion due to the habitat structure, which often contains narrow, discontinuous, and unstable supports. Arboreal squirrels tend to have longer tails than their non-arboreal counterparts as they are more effective than shorter tails in aiding in maneuverability and stability. Fox squirrels (*Sciurus niger*) use the tail primarily to aid in navigation of terminal branches while feeding and foraging. This study focuses on the differences in tail length between male and female fox squirrels; we predicted that females exhibit relatively longer tails compared to males due to gestational increases in body mass related to transport of young *in utero* and during lactation. We measured tail length, body length, and body mass of 38 squirrels trapped on Saint Mary's College Campus between May and July 2019. Our results indicate no statistical difference in male and female tail lengths. Lack of statistically significant differences in tail lengths between male and female fox squirrels may be attributed to the relatively small sample size. To substantiate the findings of this study, we plan to expand the sample size through additional data collection. Future work may explore comparisons of the balancing abilities of male and female fox squirrels during arboreal locomotion.

P35-4 Smith, JM*; Potter, RB; Pruett-Jones, SG; University of Washington, Seattle, University of California, Los Angeles, The

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University of Chicago; *smithju@uw.edu*

Win-stay, lose-shift and bower marauding: The time evolution of dispersion and destruction

Bowerbirds (Ptilonorhynchidae) are distributed in Australia and New Guinea and are best known for the fact that males build complex structures, known as bowers, for the purpose of attracting females. Bowerbirds are unique among birds in that the male's mating success is primarily based on the quality of this structure - an externalized secondary sexual characteristic - rather than on aspects of the male himself (such as plumage, song, or display). Male bowerbirds often maraud (destroy) the bowers of rivals to increase their own mating success. However, a male's decision to spend time away from his own bower can be costly, as he may miss opportunities to mate or defend his bower. In this study, we simulated interactions among males during a mating season and their decisions between mating seasons regarding how frequently to maraud and whether to relocate their bowers based on prior performance. We built a continuous-time agent-based model to represent a series of consecutive mating seasons (referred to as generations), allowing underperforming males to make stochastic adjustments between seasons. In our iterated simulations, we kept either marauding strategy (which is a continuum of rates of marauding behavior) or bower position fixed among all males and allowed the other attribute to be adjusted. We found that interactions between males alter the population's levels of bower dispersion and marauding relative to our null model (in which each male's mating success is random). These findings could inform hypotheses about the rise of marauding and of uniform bower dispersion, which might be further tested through modeling or fieldwork.

P6-3 Snyder, KP*; Greenberg, D; Mastromonaco, G; Schoof, VAM; Dept. of Biology, York University, Toronto, Canada, Div. of Experimental Medicine, McGill University, Montreal, Canda, Reproductive Sciences, Toronto Zoo, Toronto, Canada, Bilingual Biology Program, Dept. of Multidisciplinary Studies, Glendon, York University, Toronto, Canada; *snyderk@yorku.ca*

Dominance rank, age, and parasitism predict male vervet monkey (Chlorocebus pygerythrus) genital skin colouration

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Male secondary sexual characteristics may convey important information about the signaller. The red penis and blue scrotum of male vervet monkeys makes them a good species to examine variation in signal expression. We quantified colour variation (i.e., hue, saturation, luminance, contrast) in vervets at Lake Nabugabo, Uganda from standardized photos taken in May-June 2016 and Jan-June 2019. We collected agonistic data to determine male dominance rank and fecal samples for parasite and hormone analyses (n=174). Using a linear model search, we identified the ‘best’ models (lowest AICc, highest R2) to describe interindividual variation in genital color in relation to rank, mean fecal hormone metabolites, and parasite species richness (species count) and prevalence (% infected samples). Blue scrotal hue of higher-ranking males (β=5.687, F=14.096, p<0.05) and those with higher parasite prevalence (β=34.480, F=1.162, p<0.05) was teal-blue compared to true-blue in lower-ranking males and those with lower parasite prevalence, but the interaction was not significant. In contrast to blue scrotal hue, red penile saturation was predicted by the interaction of rank and prevalence (β=-2.057, F=6.761, p<0.05), with higher-ranking males with high parasite prevalence having more saturated penile coloration. Younger males had more luminant (i.e., pinker) penises than older males (β=-0.102, F=11.380, p<0.05). These results suggest that the multi-component genital signal conveys information about male age, health, and competitive ability.

P34-5 Sokolova, AM*; Voronezhskaya, EE; N.K. Koltzov Institute of Developmental Biology; *enfado@ya.ru*

Morphological background for non-canonical action of monoamines in Porifera

Representatives of the phylum Porifera are considered as organisms lacking the nervous system. Indeed, the bioinformatic analysis has confirmed the absence of monoamines receptors in the genome of four investigated sponge species. However, in two species we have found genes of 1) the full set of enzymes required for serotonin and dopamine synthesis and 2) transglutaminases required for transamidation of proteins. These data indicate that sponge cells may realize a non-canonical pathway of monoamine action via post-translational protein modification. The HPLC data and

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immunochemical labeling indicate the prevalence of the dopaminergic pathway over the serotonergic one, though serotonin- and dopamine-immunoreactive elements occur in similar locations within the cells. Using immunochemical markers, we found scattered anti-monoamine immune labels in the apical part of the choanocytes in a few demosponges and in the basal part of the choanocytes in a calcarean sponge. We also found monoamine-positive granules near the flagella in epithelia of larvae of the calcarean Clathrina arnesenae and the freshwater demosponge Eunapius fragilis. Electron microscopic study allows us to conclude that monoamine-positive structures are concentrated in the Golgi apparatus in studied sponge larvae. The obtained morphological and biochemical data indicate a non-canonical intracellular way of monoamines action in the functional activity of sponge flagellar cells. Further studies are required to confirm this suggestion. The study was supported by RFBR grants #19-34-90084 and #18-04-01213.

P31-7 Somers, S*; Davidson, G; Quinn, J; University College Cork, University Of Cambridge; *shane.somers@ucc.ie*

The gut microbiome and host fitness: microbial links to nestling growth and survival in wild great tits

The body mass achieved by juveniles before reaching independence is a key predictor of viability and fitness in many animals. While variation in the body mass of juveniles may be explained by a plethora of genetic and environmental factors, emerging evidence points to the gut microbiota as an important factor influencing host health. However, the gut microbiota is known to change during development and it is not clear whether microbiome predicts fitness, and if it does, whether this is reflective of current or future condition. We collected data on nestling weight and survival to fledging as key traits associated with animal fitness. We investigated temporal associations between great tit gut microbiome and fitness across development by sampling nestling faeces as a proxy for gut microbiome at day 8 and day 15 post-hatching. We also investigated whether particular microbial taxa were 'indicator species' for birds that survived, and birds that did not survive. There was no link between contemporary weight and microbial diversity at day 8 or day 15. However, weight at day 15 was negatively associated with gut microbial diversity at day 8. Three

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Lactobacillaceae spp. were identified as 'indicator species' for birds that survived, and at least one of which was also associated with future weight gain, suggesting that some Lactobacillaceae taxa could be used as a marker for predicting natal viability. We highlight that microbial-host fitness effects should be investigated longitudinally as there may be critical development windows in which key microbiota are established and prime host traits associated with nestling growth such as digestive and/or immune functions. Pinpointing which features of the gut microbial community impact on host fitness, and when, will shed light on evolutionary processes and inform conservation practices.

P35-5 Spezie, G*; Fusani, L; University of Veterinary Medicine, Vienna, Austria, Department of Behavioural and Cognitive Biology, University of Vienna, Vienna,
Austria; *giovanni.spezie@vetmeduni.ac.at*

Learning to be attractive: investigating the role of learning in the expression of complex sexual signals

Spotted bowerbirds (*Ptilonorhynchus maculatus*) build and decorate complex stick structures on their display arenas - the bower - and use it as a stage to perform a dance choreography to visiting females. Our project is focused on the behavior of immature and non-territorial male bowerbirds, which attend established bowers as auxiliary males and are tolerated by local bower owners. Several observations suggest that auxiliary males may acquire information concerning the mature form of courtship from these tutors. Patterns of similarities in the type and color of the displayed decorations suggest the existence of local traditions and social learning. While this evidence relates to construction abilities and decoration choice, little is known about the dance components of courtship. We used automated cameras to investigate whether the motor performance of these auxiliary males undergoes gradual refinement via practice and whether consistent similarities in the postural elements of courtship exist between auxiliary males and their tutors. The variables taken into consideration include the proportion of display elements, their sequence within a display bout and their fine-scale properties (e.g. duration). We present the analysis of some features of dance performance and preliminary results regarding the variables of interest.

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P28-9 Spiessberger, EL*; Betz, O; Eberhard Karls Universität Tübingen; *erich.spiessberger@uni-tuebingen.de*

Comparative head morphology of predaceous (Staphylininae) and mycophagous (Oxyporinae) rove beetles (Staphylinidae, Coleoptera)

The head morphology of *Platydracus femoratus* (Fabricius, 1801), representative of the Staphylininae, and *Oxyporus stygicus* Say, 1834, representative of Oxyporinae are presented. The analysis of mandibles, maxillae, labrum-epipharynx and labium-hypopharynx through scanning electron microscopy (SEM) are shown in detail regarding the external morphology. The analysis of the tentorium and the hypopharynx and prementum sclerites through 3D reconstruction of Synchrotron X-ray microtomography (SR-µCT) scans are shown in detail regarding the internal morphology. The scope of this project is to provide a comprehensive general survey of the external and internal head morphology of various monophyletic subfamilies previously assigned to the traditional Staphylinine group. In addition to the study of sclerotized parts, the project will also cover the head musculature, providing the points of origin of insertion of the muscles inside the head capsule. These results are part of a larger project that will count with the same methodology applied herein for other 34 species of the Staphylinine group. By comparing both the external mouthparts and the internal head morphology of species covering the major clades among the Staphylinine group, we aim at interpreting the functional head morphology on the basis of a phylogenetic scheme of this group. The study of the head and mouthparts morphology of modern Staphylinidae has been neglected so far, and the aim of this project is also to provide such information for a better understanding of the higher-level classification of the Staphylinine group.

P28-4 Spinelli, J*; Huynh, A; Rice, A; Lehigh University; *jcs518@lehigh.edu*

Learning the "chick-a-dee" call: Implications for reproductive isolation in sympatry

The role of avian song in speciation is widely studied, but how avian calls contribute to speciation remains largely unknown. Although song is typically used only by males for reproductive

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purposes, calls are used by both sexes, across most species, and throughout the year. Calls are assumed to be innate, but some species learn calls and adjust acoustic characteristics based on experience. The contexts in which calls occur are important for fitness, including species recognition, foraging, and defending territories. Therefore, in sympatry, multiple aspects of fitness could be affected by the ability of an individual to learn calls and discriminate between con- and heterospecific calls. We used the black-capped and Carolina chickadee and their naturally occurring hybrids to test two hypotheses about call learning. The black-capped and Carolina chickadee both use similar versions of the well-known "chick-a-dee" call. The chick-a-dee call has a variety of uses, including both individual- and species-level recognition. We hypothesized that each species would be biased towards learning conspecific calls; and that hybrids would exhibit reduced ability to learn either of the parental species' calls. We hand reared wild-caught chickadee nestlings from hybrid zone populations in a controlled environment. We exposed all birds to playbacks of Carolina and black-capped calls for two months, and then recorded each of the bird's calls. To test for biases towards learning one species' call over the other, we measured the frequency of species-specific notes in all recorded calls. To test for the relative call learning ability of parental species versus hybrids, we compared the similarity of each bird's call to the playbacks. Results from this project will provide insight into the potential for avian calls and call learning to contribute to pre- and post-zygotic reproductive isolation.

P36-4 Spriggs, SN*; Cost, IN; Albright College; *suzanne.spriggs001@albright.edu*

A comparative analysis of the remote touch mechanism in birds

Touch is an integral sense in the development of all animals. Birds and crocodiles have similar anatomical plans and thus should have similar facial innervation. Crocodilians are covered with dome pressure receptors (DPRs) that send signals of pressure changes to the brain via the trigeminal nerve, which has three branches (V_1, V_2, and V_3). Bird remote touch sensation effected through Grandry and Herbst corpuscles, is also transmitted to the brain via the trigeminal nerve. In remote touch sensitive birds, mechanoreceptor

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abundance is highest in the bill tip organ. The bill tip organ is known to exist in four families of birds; Apterygidae, Scolopacidae, Anatidae, and Threskiornithidae. We conducted a review of current literature and known trigeminal nerve maps for birds and crocodilians. Based on the literature, we predict that probing birds will have more branched trigeminal nerve (V_1 and V_2) divisions. We created nerve maps (V_1 and V_2) of a Black-crowned Night-heron (*Nycticorax nycticorax*) and a Virginia Rail (*Rallus limicola*) by using manual dissection. Photographs and measurements were taken during dissection. Measurements of overall trigeminal nerve and segment length were taken by using calipers and scale bars associated with photographs. These were used to compare overall trigeminal nerve distribution in species of birds that utilize spearing (*N. nycticorax*) and species of birds that utilize probing (*R. limicola*) when finding food. Preliminary examination of the trigeminal nerve in birds appears to support our prediction. Our study provides more complete nerve maps of shorebirds and provides connections between degree of trigeminal nerve branching and the ability to use remote touch. Our nerve maps offer a more complete understanding of remote touch sensation which is essential to conservation of shorebirds.

P27-9 Stansberry, KR*; Kelly, TR; Lattin, CR; Louisiana State University, Baton Rouge, LA; *kstans6@lsu.edu*

Increased phagocytic capability prior to experimental malaria inoculation may reduce likelihood of infection at no cost to body condition

A warming climate is expected to increase the prevalence of avian malaria over time, partly due to the range expansion of mosquito vectors. One factor contributing to an animal's ability to resist parasitic infection is the increase in phagocytic activity of macrophages throughout the body. In the case of infection, animals with increased phagocytic capability are expected to show resistance to malaria infection and this may mitigate negative effects on body condition. However, the energetic costs of phagocytosis may trade-off against body condition. To test for such trade-offs, we conducted in vitro assays of whole blood phagocytic capability in the presence of fluorescent *E. coli* and *S. aureus* before and after inoculating captive House Sparrows (*Passer*

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domesticus) with malaria (*Plasmodium sp.*) or control injections. Although sample sizes were small, we found a moderate trend where House Sparrows with increased phagocytic ability of *E. coli* prior to inoculation were more likely to resist malaria infection compared to conspecifics with reduced phagocytic ability. However, resistant and successfully infected birds did not differ in body condition (mass, fat score, change in blood glucose) at the crisis stage of infection. These preliminary results suggest that phagocytosis does not tradeoff with body condition at the crisis stage of infection.

P30-7 Stanton, DS*; He, H; Liu, AC; University of Florida, Gainesville FL, University of Florida , Gainesville FL; *stantond2@ufl.edu*

Developing circadian clock reporter cell lines using a CRISPR gene editing knockin approach

Circadian rhythms are important in the regulation of physiology and behavior of animals. The molecular clock underlying these rhythms is based on a transcriptional/translational negative feedback mechanism, in which transcriptional activators BMAL1 and CLOCK regulate the expression of their own repressors PER1, PER2, CRY1 and CRY2. Nucleocytoplasmic translocation of the negative regulators play key roles in establishing circadian oscillations. However, the precise spatiotemporal dynamics and regulatory mechanisms of PER and CRY are not well understood. Many studies use molecular methods to gain a snapshot perspective of the translocation process, however this prohibits the visualization circadian protein movement in time and space within a single cell. In our study, we leverage our understanding of previously developed cellular clock models including human U2OS osteosarcoma cells and mouse MMH-D3 hepatocytes that display cell-autonomous robust circadian rhythms, permitting mechanistic studies in single cells with spatial-temporal resolution. Here, we present the development of circadian reporter cell lines using CRISPR-Cas9 gene editing technology to knockin fluorescent reporter genes in the N or C terminus of PER and CRY proteins. Studies using these developed cell lines will improve our understanding of circadian negative regulator translocation dynamics in response to pharmaceuticals,

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nutrition, and disease pertubations with spatiotemporal resolution in a single cell.

P21-7 Steer, KE*; Edmonds, CE; Gould, FDH; Adjerid, K; Bond, LE; German, RZ; Mayerl, CJ; NEOMED, Rootstown OH, Rowan School of Osteopathic Medicine, Stratford NJ; *kes179@zips.uakron.edu*
The impact of automated milk delivery on infant feeding performance
Infant feeding is a complex process involving the acquisition, transport, and swallowing of food using multiple structures including the tongue, jaws, palate, pharynx and the larynx. Infants acquire food by depressing the mandible and tongue to draw milk from the breast into the oral cavity. Following food acquisition, the tongue moves in a wave posteriorly to transport food to the valleculae and prepare for swallowing. Swallowing is then triggered by sensory stimulation in the valleculae. Here, we tested whether the automated delivery of milk would impact infant feeding performance. We surgically implanted radiopaque markers into three points on the tongue, as well as on the mental process, hyoid, and soft palate. We filmed infant pigs using biplanar videofluoroscopy (100 fps) when feeding on a bottle and at two different automated volume delivery rates. We found that the anterior tongue moved significantly more when sucking during bottle feeding than during automated milk delivery. Furthermore, we found that during swallowing the posterior tongue moved significantly more when bottle feeding than during automated milk delivery. These results suggest that automated milk delivery results in reduced tongue movement, which impacts both the parts of the tongue involved in suction generation (anterior) and swallowing (posterior). By delivering milk using an automated system, the tongue is likely generating less suction, which has downstream impacts on feeding performance. Thus, understanding the sensorimotor integration involved in infant feeding will improve our understanding of the physiology of infant feeding, and improve infant health for compromised populations.

P29-5 Steffen, JBM*; Haider, F; Sokolov, EP; Sokolova, IM; University of Rostock, Germany, Leibniz-Institute for Baltic

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Research, Warnemuende, Germany; *jennifer.steffen@uni-rostock.de*
Mitochondrial capacity and reactive oxygen species production in response to short-term hypoxia and reoxygenation in the ocean quahog, Arctica islandica
Oxygen fluctuation is a common phenomenon in marine waters. Hypoxia/reoxygenation (H/R) stress can negatively affect energy metabolism, since oxygen deficiency impairs mitochondrial ATP generation, whereas a surplus of oxygen causes mitochondrial damage by oxidative stress mechanisms. The long lived ocean quahog, *Arctica islandica*, is known for its hypoxia tolerance associated metabolic rate depression, yet the underlying mechanisms that sustain their mitochondrial integrity and function during oxygen fluctuations are not yet well understood. We used the top-down metabolic control analysis (MCA) to determine mitochondrial capacity and control of mitochondrial subsystems over bioenergetics in response to short-term hypoxia (24h <0.01% O_2) and subsequent reoxygenation (1.5h 21% O_2) in the hypoxia tolerant ocean quahog with control animals kept under normoxic conditions (21% O_2). We hypothesised that the ocean quahog shows a coordinated reorganization of its mitochondrial subsystems and regulated reactive oxygen species (ROS) production to maintain mitochondrial functions contributing to its H/R resilience. To test these hypotheses, mitochondrial oxygen flux capacity and control over the respiratory flux of hepatopancreas mitochondria of the studied species were analysed by high resolution respirometry, along with simultaneous fluorometric ROS production associated with membrane potential changes. The results of this study shed light on mechanisms of mitochondrial flux control and resilience to hypoxia in stress-tolerant marine bivalves.

P12-8 Stephens, S*; Gabriel, AN; Kaczmarek, E; Brainerd, EL; Olsen, A; Hernandez, LP; Camp, A; Farina, SC; Howard University, Brown University, Brown University, The George Washington University, The University of Liverpool; *sydney.stephens@bison.howard.edu*
The role of cranial mechanical linkages in gill ventilation of dorso-ventrally and laterally compressed fishes
Teleost fishes pump water over their gills by cyclically expanding and compressing the buccal and gill chambers. These chambers are typically modeled as coordinated but operating as independent

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components of the pumping process. The chambers are mechanically linked, however, and these linkages play an underappreciated role in ventilatory mechanics. Our goal is to quantify the extent to which these linkages impact ventilatory kinematics. In this study, we focus on the suspensorium-opercle linkage, by which abduction of the suspensorium (buccal chamber) contributes to abduction of the opercle (gill chamber). We calculated these values from XROMM (X-ray Reconstruction of Moving Morphology) animations of catfish (*Ictalurus punctatus*) and knifefish (*Chitala blanci*) ventilatory sequences. In the catfish, we found that abduction of the suspensorium contributes 46-70% to the abduction of the operculum during gill ventilation. However, in the knifefish, we found that abduction of the suspensorium contributed much less, only 30-33%, of abduction of the operculum. The catfish skull is dorso-ventrally compressed, and the knifefish skull is laterally compressed, representing two extremes of fish skull shape. While suspensorium abduction contributes to opercular abduction in both fishes, the relative extent of that contribution may be linked to head shape.

P39-11 Stormer, HG*; Proctor, HC; University of Alberta; *hstormer@ualberta.ca*

Snail-fur symbionts: microscopic comparison of two species of ectosymbiotic peritrich ciliates (Ciliophora: cf. Scyphidia spp.) from freshwater snails

Freshwater snails host a diverse array of symbionts, including many protists. Examination of snails from the families Physidae, Lymnaeidae and Planorbidae from Alberta, Canada, revealed transparent "fur" covering the body and tentacles of some individuals; others had similar green material lining the inside of the pulmonary cavity (lung). SEM images revealed the "fur" to be peritrich protists potentially from the genus *Scyphidia* (hereafter we use ‘scyphidia’ as a common name) with the color in green individuals due to symbiotic algae resembling *Chlorella*. The clear scyphidia are morphologically similar to *Scyphidia physarum* Lachman; the green scyphidia appear to be an undescribed species. SSU rRNA from the green scyphidia from Alberta was 99% identical to snail-associated scyphidia in Massachusetts - the only previous observation of this species. TEM, SEM and histology showed consistent morphological differences, suggesting the two scyphidia

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are different species rather than one species with and without algal symbionts. Both seem to cause little to no snail tissue damage at the attachment site; attachment appears to be aided by protrusions of the scopular tissue into gaps between snail epithelial cells. Examination of snails from 8 sites in Alberta suggest that clear scyphidia are common (all sites) and green scyphidia are relatively rare (4 sites). Both are found on Physidae and Planorbidae and can co-occur on the same snail; clear scyphidia also occur on Lymnaeidae. Each is specific to a region on the snail, with the green scyphidia in the left side of the lung and clear scyphidia on the body and tentacles. When the snail hosts were kept in the dark, results were mixed as to whether each kind of scyphidia remained or disappeared.

P14-5 Stover, KK*; Hanna, JB; Benson, MA; Liu, T; Pankey, CL; WVSOM; *kstover@osteo.wvsom.edu*

Introducing undergraduates to their first research experience using a virtual format

The First2 Network is an alliance of institutions across West Virginia striving to support rural, first-generation, and underrepresented college students in STEM. Past faculty have mentored students in their lab for two weeks, prior to the student beginning their freshman year, initiating the students' STEM network and providing their first research opportunity. Due to COVID-19, we designed a collaborative research project that would be done from the students' home with materials that could be mailed. We used a citizen science project (EarthEcho Water Challenge) to test water quality parameters and sent students microscopes to identify microorganisms in the sampled water. We met virtually each morning and discussed research topics such as Microscope Training, Developing Hypotheses, etc. Early afternoons were set aside for students to collect samples, identify microorganisms, and input data into a shared database. Late afternoons were reserved for professional development, and evenings for team building activities led by student mentors. The two-week session culminated in presentations based on hypotheses and analyses the students designed collaboratively. Students were asked to complete a survey before (n=5) and after (n=4) the research experience, which revealed increased ($p<0.05$) rating of "knowledge

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of research", and "research skills" subscales. Students also reported that the experience made them "excited to enter a STEM field" and they "better understood the process of conducting research". Faculty felt the common database and shared data collection techniques facilitated in fostering a good group dynamic and permitted the students to engage in metacognition about research, rather than learning a specific technique.

P32-5 Strong, JBE*; Akanyeti, O; University of Aberystwyth, Computer Science, Aberystwyth; *jes15@aber.ac.uk*

Achieving swarm cohesion and exploration using simple sensory feedback

Animal groups often exhibit enhanced capabilities that are outside the realm of a single individual. Our research aims to better understand what variables, processes and mechanisms control these beneficial emergent behaviours. Comprehension of these has exciting implications in understanding the building blocks of biological swarms and in the implementation of computerised applications and robotic platforms. Previous research has shown how simple, locally controlled rules of interaction can lead to robust group behaviours. Inspired by that work and from biological observations, we propose a novel behaviour selection algorithm that allows groups to effectively explore while maintaining unity. Using multi-agent computer simulations, we show that if individuals maintain close proximity with approximately six neighbours, the whole group can be coherent and mobile at the same time regardless of the group size and speed. Staying together as a coherent unit is a challenging task especially in fast moving groups and our algorithm, which is based on a simple sensory feedback, shows how these two often opposing behaviours can be consolidated to improve efficiency.

P20-8 Sum, J*; Montooth, KL; Matoo, OB; DeWitt, H; University of Nebraska-Lincoln, Lincoln, NE , University of Nebraska-Lincoln, Lincoln, NE; *joevysum@gmail.com*

Uncoupling proteins as a physiological defense mechanism in Drosophila

Most organisms produce energy using oxygen to make ATP via oxidative phosphorylation (OXPHOS) in the mitochondria. This

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process generates reactive oxygen species (ROS), which is beneficial in moderation for various metabolic processes like growth and signal transduction. However, elevated ROS levels are harmful as they are highly reactive, causing oxidative damage to cells, which may lead to mitochondrial dysfunctional diseases such as Parkinson's and Alzheimer's. In response, cells may produce uncoupling proteins (UCPs) that diffuse some of the electrochemical gradient that builds up in the mitochondria. My proposed research project will test this framework, using the model organism *Drosophila* because of the ease of genetic manipulation and the presence of mammalian UCP homologs. This project will address the knowledge gap of the UCPs in flies and invertebrates where mammalian UCPs are well defined in their role of heat production during hibernation. Therefore, we think that UCPs may be a critical cellular defense mechanism in these highly aerobic organisms. With the current effects of climate change, many ectotherms such as insects will be facing increased energetic stress which will likely result in more ROS production. With this, a deeper investigation into uncoupling of the mitochondria would aid in the process of understanding the way insects will cope with climate change as well as investigating *Drosophila* as a potential alternative model for in vivo UCP studies.

P1-6 Sweis, J*; Krohmer, RW; Saint Xavier University, Chicago ; *sweis.j05@mymail.sxu.edu*

Seasonal distribution of arginine vasotocin in the forebrain of male red-sided garter snakes

Arginine vasotocin (AVT) is a potent regulator of social behavior in many species, but little is known about its role in reptilian behavior. Preliminary studies suggest that AVT may play a role in the mating behavior of male red-sided garter snakes (RSGS). Here, we analyzed the role of seasons on the distribution of AVT in the forebrain of male RSGS. Findings from this study will point to a potential time course for AVT in cellar mechanisms responsible for reproductive behavior.

P35-7 Tait, CC*; Nedeljkovic, K; Olson, MN; Katz, PS; University of Massachusetts Amherst; *ctait@umass.edu*

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Population density and the reproductive hormone conopressin affect the mating behavior of the nudibranch Berghia stephanieae differently

Some aspects of mating behaviors shift in response to external context, which may be mediated in part by hormonal mechanisms. We examined the influence of population density on mating behavior of the hermaphroditic nudibranch, *Berghia stephanieae*. Individuals were reared communally (high density) or with one partner (low density). We video-recorded mating between test pairs and, using tracking software to quantify movement, constructed behavioral ethograms of courtship sequences. We found that when a test pair included an individual from a low-density environment mating duration decreased, with post-copulatory mate guarding often omitted. We also found that test pairs exhibiting similar, intermediate crawling speeds were more likely to mate. Fast or slow individuals often did not interact, perhaps indicating they were not in a state conducive for mating (e.g. startled, hungry). It is known from other species that temporary internal states can have strong impacts on mating behavior and that shifts in hormone levels can occur in response to social environment and induce behavioral change. We therefore tested the effect of conopressin, homologous to mammalian oxytocin/vasopressin. Conopressin, when bath-applied at nanomolar concentration, decreased latency to mating. However, unlike the effect of low-density rearing, conopressin did not affect mating duration or sequence. Likely a cascade of internal mechanisms, more complex than a single hormone, is responsible for the effect of rearing. In summary, we found that prior social environment altered mating dramatically, changing both the sequence and dynamics of the behavior, whereas conopressin had only a transient effect on latency rather than overall characteristics of courtship.

P17-9 Tan, MT*; Chen, T; Suzuki, Y; Wellesley College; *mtan3@wellesley.edu*

Deciphering the origin of metamorphosis through epigenetics

Holometabolous insects, which have distinct larval and pupal stages, evolved among hemimetabolous insects, which have nymphal stages. Currently, there are two main theories to explain how metamorphosis evolved, but the issue remains unresolved. To address

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this issue, we have been investigating the roles of histone modifiers in a holometabolous insect, the red flour beetle *Tribolium castaneum*, and a hemimetabolous insect, the milkweed bug *Oncopeltus fasciatus*. In *T. castaneum*, knock down of the epigenetic regulators *Polycomb* (*Pc*) and *Enhancer of zeste* (*E(z)*) during the pupal stage led to drastic homeotic transformations in the adults. This demonstrates that Pc and E(z) play key roles in determining segmental identity during metamorphosis. We are currently researching the roles of Pc and E(z) in the development of *Oncopeltus fasciatus*, a species of hemimetabolous insects. We will present data comparing the timing of action of Pc and E(z) through the use of RNA interference and through the use of quantitative PCR. The results from this study may help clarify the evolution of insect metamorphosis.

P13-2 Taraporevala, N*; Goodheart, J; Masterson, P; Johnston, H; Babonis, L; Lyons, D; University of California, San Diego, Cornell University; *nftarapo@ucsd.edu*

Using laboratory culture of the nudibranch Berghia stephanieae to study reproductive development and feeding behavior

Historically, nudibranch molluscs have been useful for studies of animal behavior and neurobiology, but their life history is hard to study as most species cannot be cultured through the entire life cycle in the lab. The aeolid nudibranch *Berghia stephanieae*, often used to keep ornamental corals free of the anemone *Exaiptasia pallida*, can be cultured through many generations in the lab in inland aquaria. Using a precise culturing method to raise individual egg masses of known age along with a detailed staging system, we will accomplish the following goals: 1. Determine precisely how early in development *Berghia* first mate, using their ability to grow in isolation. Preliminary studies have indicated that mating occurs before gamete maturity is obvious. Although they are reciprocally copulating hermaphrodites, this suggests that individuals may exchange and store sperm before they can produce eggs. 2. Determine the specific stages of the maturation of gametes prior to oviposition. Due to their translucence, we have observed eggs forming in an organized pattern, making the animal appear gravid. 3. Determine the factors that allow *Berghia* to consume different prey species. *Berghia* have previously been observed to be

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stenophagous, preying solely on *Exaiptasia*. However, we have documented some *Berghia* preying on the anemone *Nematostella vectensis* in certain contexts, showing that their diet may be broader than originally thought. Collectively, these factors allow us to improve the culture of *Berghia* by learning about its reproductive development and feeding behavior.

P24-5 Teemer, SR*; Hawley, DM; Virginia Tech; *steemer@vt.edu*
Effect of temperature on behavior and contact rates in house finches
Contact rates relevant for pathogen spread are shaped by behavior, and in turn, behaviors of susceptible and infected hosts are influenced by abiotic factors such as temperature. House finches (*Haemorhous mexicanus*), a songbird species, can become infected with the bacterial pathogen *Mycoplasma gallisepticum* (MG) through direct contact with infected conspecifics or indirect contact via shared use of bird feeders. Outbreaks of MG, which causes the disease mycoplasmal conjunctivitis, primarily occur in fall and winter. During these periods of colder temperature, house finches rely on bird feeders to meet increased energy demands, which may increase rates of direct and indirect contacts between infected and uninfected birds. However, the role of ambient temperature in driving behaviors relevant to transmission has not been studied. To determine how temperature influences behaviors and contact rates important for MG spread, we manipulated ambient temperatures (thermoneutral or subthermoneutral) for pair-housed birds and quantified feeding behaviors. We measured contact rates using a fluorescent transferrable powder applied around the conjunctiva of one "index" bird per pair to mimic MG spread and quantified the amount of powder transferred to cagemates directly or indirectly at several time points. To account for effects of sickness behavior on behavior and contact rates, half of the index birds in each temperature group were given lipopolysaccharide injections to induce sickness behaviors similar to those in birds infected with MG. Because behavior and contact rates are integral in determining likelihood of pathogen spread, it is important to understand the factors that affect both components. Thus, this experiment can provide insight into the role of the abiotic environment on

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transmission in this system and other infectious diseases more broadly.

P12-7 Teeple, JB*; Paig-Tran, EWM; California State University, Fullerton; *julia.teeple@csu.fullerton.edu*

Tiny teeth in mega filter-feeders - vestigial or functional?

The planktivorous sharks (*Rhincodon typus*, *Cetorhinus maximus*, and *Megachasma pelagios*) filter zooplankton using elaborate branchial filters. Each filter-feeding shark retains large numbers of highly curved teeth (ex. 300 rows in whale shark, 100-150 rows in basking shark, and 90 rows in megamouth). We ask, are these teeth vestigial structures or are they functioning in a similar manner as placoid scales. Our study used anatomical measurements of teeth from the three planktivorous sharks (height, width, spacing, and surface curvature) to build, 3-D physical and computational models. We found that tooth shapes and spacing are vastly different among species. The filter-feeding sharks' teeth are convergent in form and greatly differ from their closest extant relatives. For example, *Stegostoma fasciatum* teeth are relatively straight and tricuspid, while the closely related whale sharks have a curved, singular cusp. Previous work on placoid scales (dermal denticles) showed that a ratio of height to spacing (H:S) of 0.5 and a ratio of thickness to spacing (T:S) of 0.03 produces maximum drag reduction. The higher H:S and T:S ratios in whale sharks and basking sharks should result in an increased drag (H:S = 1.75, T:S = 0.33 and H:S = 0.68, T:S = 0.86 respectively). Megamouth shark has a lower H:S ratio; however, the higher T:S ratio should also result in increased drag (H:S = 0.27, T:S = 1.79). Increased drag at the mouth opening may help to laminarize flow directed toward the anteriorly located filter elements. Laminarized flow across the filters promotes both cross-flow and ricochet filtration during feeding events.

P30-4 Terry, J*; Fiedor, T; Veach, MV; Vickrey, CV; Neuman-Lee, LA; Arkansas State University - Jonesboro; *jennifer.terry@smail.astate.edu*

Ecophysiological tradeoffs in female red-eared sliders (Trachemys scripta)

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Freshwater turtles, a long-lived group with multiple reproductive opportunities throughout their lives, must allocate finite energy and resources to reproduction, self-maintenance, growth, and basal processes. Energy allocation dynamics are expected to shift respective to clutch development, gravidity, and post-oviposition in females as these processes demand different profiles of resources and have varied energetic requirements. Further, clutch development investment may vary throughout the reproductive season in multiclutching individuals. We captured native red-eared sliders (*Trachemys scripta*), a multiclutching population, in the Delta Region of Arkansas and collected blood samples, recorded morphometrics, and conducted reproductive assessments via ultrasound between May and October 2019 and in June 2020. We performed bacterial killing assays and radioimmunoassays to assess innate immune function and hormone concentrations, respectively. Ovarian status was qualitatively scored based on presence of follicles, atretic follicles, and eggs. By determining how these abundant reptiles allocate their energy during obligatory processes, such as reproduction, we can better address questions within the fields of conservation and comparative ecophysiology.

P41-6 Thomas, NT*; O'Brien, HD; Gignac, PM; McGowan, CP; Collins, CE; Sacramento State University, OSU Center for Health Sciences, University of Southern California; *nimmythomas@csus.edu*

Do ankle extensor muscles match locomotor behavior in rodents?

The hindlimb hypertrophy and augmented power in the limb extensor musculature of bipedal rodents, like kangaroo rats and jerboas, hypothetically better equip them to escape depredation than their quadrupedal counterparts. Visualizing and measuring hindlimb musculature allows us to better understand the differences that elicit rapid responses in bipedal rodents needed to escape from incoming predators. We used DiceCT and digital segmentation to visualize and measure the volume of the ankle extensor muscle of 14 rodent species, representing two bipedal lineages alongside quadrupedal outgroups. Generally, bipedal rodents had larger ankle extensors relative to their body size. For example, *Dipodomys ordii*, a North American Heteromyid, has the most massive lateral gastrocnemius relative to body size. However, *Napaeozapus insignis* also has large ankle extensors relative to body size. They

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represent an "intermediate'' between quadrupeds and bipeds and are known for explosive jumps. We report a reduced or absent soleus muscle in bipedal Dipodidae. Our data supports the hypothesis that bipedal rodents have larger and thus more powerful ankle extensor muscles that facilitate powerful leaps in order to escape from potential threats such as those from an owl or rattlesnake attack. We propose that bipedal hopping likely coevolved with larger ankle extensors to perform these explosive, high-powered jumps. We contrast the putatively convergent morphological adaptations of kangaroo rat and jerboa lineages and discuss their evolutionary trajectories relative to quadrupedal counterparts.

P34-4 Thoroughgood, DNF*; Newcomb, JM; New England College; *DThoroughgood_UG@nec.edu*

Regeneration of autotomized cerata in Berghia stephanieae

Regeneration has been extensively studied in certain groups of invertebrates, such as flatworms, and often occurs after autotomization, in which animals sacrifice a body part to escape from predators. Nudibranchs can autotomize cerata, which are dorsal appendages that contain extensions of the digestive system and can also sometimes be used for respiration. The nudibranch *Hermissenda crassicornis* can regenerate autotomized cerata, so we hypothesize that a species in the same suborder, *Berghia stephanieae*, can also regenerate autotomized cerata. To test this hypothesis, five cerata were pinched at their base to promote autotomy of the appendage, from either the anterior (n = 10) or medial (n = 7) region of the animal. The growth of the cerata were measured 2-5 days after initial autotomy, and then every 2-3 days after that for a total of 3 weeks. Initial regeneration of autotomized cerata was visible after 2-3 days and continued at an average rate of 0.09 mm per day. Cerata regained ~90% of their original length after 23-24 days. Anecdotal observations suggest that these regenerated cerata exhibited peristaltic movement after feeding, and thus may have reacquired functionality during this period, as well. Thus, *B. stephanieae* can regenerate autotomized cerata and may provide a good opportunity for investigating regeneration in a lophotrochozoan outside of the commonly studied flatworms.

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P27-5 Titon, SCM; Titon Jr, B; Floreste, FR*; Garcia Neto, PG; Lima, AS; Ferreira, LF; Vasconcellos-Teixeira, R; Gomes, FR; Assis, VR; University of Sao Paulo, Santo Andre Foundation University Center; *felipe.floreste@gmail.com*

Day vs. night: LPS effects on immunity and hormone mediators in toads

In recent years, the lipopolysaccharide (LPS)-induced immune-endocrine interactions and its implications have been demonstrated in amphibians. Moreover, when considering immune challenges, the immune-endocrine alterations can vary with time of injection (day or night). In this study, we explored the LPS effects on the immune response (plasma bacterial killing ability - BKA, phagocytosis of blood cells - PP, and neutrophil: lymphocyte ratio - NLR) and endocrine mediators (corticosterone - CORT and melatonin - MEL plasma levels) in *Rhinella icterica* toads injected at day (10h) and night (22h). Our results showed LPS-induced increases in CORT, NLR, and PP when compared with saline-treated individuals. For NLR, the increase happened at both times (day and night) in the LPS-treated toads. Interestingly, for CORT levels, the response was more pronounced during the night, while for the PP, the effect was more evident during the day. However, no changes were observed in BKA and plasma MEL levels. Overall, our preliminary results demonstrated the LPS-injection promoting inflammatory response in *R. icterica* toads (higher PP and NLR), followed by activation of the hypothalamic-pituitary-interrenal axis (higher CORT levels) at both times of stimulation. Additionally, when the toads received the immune challenge (day or night) can differently favor the endocrine and immune mediators. It is also worth highlighting the relevance of investigating distinct immune components (cellular and protein) for a better understanding of the LPS-induced immunomodulation.

P5-6 Toh, MWA*; Lobert, GT; Moran, AL; University of Hawai'i at Mānoa; *tohmw@hawaii.edu*

Energy use during the development of two species of Antarctic sea spider

Many marine invertebrates brood their young and use various methods to supply energy to their offspring, such as yolk in the egg, parental secretion of nutrients, or trophic eggs. In sea spiders

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(Arthropoda: Pycnogonida), the male broods the eggs. Brooding is prolonged in many Antarctic species, and larvae molt through several stages while clinging on to the egg mass. The energetic cost of development and the source of this energy are both unknown. We characterized patterns of organic mass loss in the developing embryos and larvae of two species of Antarctic sea spider, *Ammothea glacialis* and *Nymphon australe*. Both species brood larvae to an advanced stage, with larvae undergoing three molts while clinging to the egg mass. We collected egg-bearing males from four dive sites in McMurdo Sound, Antarctica, between October 2019 and January 2020. We measured the ash-free dry weight of multiple subsets of five offspring from each stage, with each subset sampled from a different egg mass (n = 10, 8, 8, 8 and n = 11, 9, 14, 13 for the eggs, Stage 1, Stage 2 and Stage 3 larvae of *A. glacialis* and *N. australe* respectively). Organic mass declined significantly between each consecutive stage for *A. glacialis* (total loss of 15.4 ± 3.2μg, 28.6% of the egg's AFDW), and between the egg, Stage 1 and Stage 2 larva of *N. australe* (total loss of 25.3 ± 3.7μg, 34.6% of the egg's AFDW). However, the Stage 3 larvae of *N. australe* displayed a significant increase in biomass as compared to the Stage 2s. While the source of this energy is yet unknown, it may be due to feeding, either on siblings or organic detritus. Our findings suggest that development is fueled largely by yolk reserves in brooding sea spiders, but that later stages of some species supplement nutrition by exogenous feeding. Funded by NSF-OPP-1745130 to ALM.

P29-2 Tomlinson, B*; May, MA; Tomanek, L; California Polytechnic State University, San Luis Obispo, Florida Gulf Coast University; *brietomlinson@hotmail.com*

The role of sirtuins in linking the oxidative stress response and food ration

The California mussel, *Mytilus californianus*, is a model organism for the physiological adaptations to the rocky intertidal zone. Due to their sessile nature, their physiological responses to environmental stressors (like heat stress) provide indication of when further climate change starts to be detrimental. Sirtuins are involved in regulating antioxidant systems, such as the glutathione system, during stress through post-translational modifications.

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Previous studies suggest sirtuins are activated by caloric restriction and are involved in the heat shock response of mussels. In this study, we investigated if sirtuins affected the stress response of *M. californianus* (i.e. the antioxidant capacity of the glutathione system) to heat stress. Furthermore, we investigated if algal ration affected the mussels' response to these stressors. Mussels were fed a low or high algal food ration for 3 wk before exposure to one of four conditions: (A) acute aerial heat stress (33° C), (B) sirtuin inhibition, (C) acute heat shock following sirtuin inhibition, or (D) no treatment. Confirming previous experiments, sirtuin activity was higher in mussels fed a low food ration compared to the high ration mussels. Additionally, we observed an increase in SIRT5 abundance 4 hours after sirtuin inhibition (regardless of ration) and increased GSH:GSSG in mussels acclimated to the low food ration following exposure to either acute heat stress or sirtuin inhibition (but not both) compared to high food ration mussels. Our findings suggest that sirtuins, possibly activated by low food intake and/or acute heat stress, are involved in the mussels' glutathione system, and may be important regulators of the oxidative stress response.

P21-6 Trainor, S; Donatelli, CM; Kolmann, MA; Summers, AP; Summers, DS*; Kruppert, S; Rice University, University of Ottawa, Department of Biology, University of Michigan, University of Washington, Friday Harbor Labs; *dexter@mightycheese.com*

How to eat a boxed lunch - crabs feeding on armored poachers

Poachers (Agonidae) are a group of bottom-dwelling fishes characterized by their bony armor. Though these fish are heavily armored, they still face predatory pressures. We have CT and SEM data from more than 30 Northern Spearnose Poachers that show extensive damage to their bony plates. A potential threat in their natural habitat is the Red Rock crab (*Cancer productus*), which typically use their claws to process prey. We are interested in whether the damage that we see done to the armor could be caused by Red Rock crab claws. To this end, we gathered video of Red Rock crabs eating agonid carcasses using a GoPro rig and analyzed their feeding behavior. We then collected the damaged scales and imaged the damage done by the crab in a scanning electron microscope. The damage we found matched up with our previous images of damaged

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poacher plates. We were able to replicate the damage with machine milled crab claws in a material testing system and our data confirms the crab's capability to crush through *Agonopsis vulsa's* armor. We found that the damage applied by the material testing system and natural crab predation were similar enough to conclude that there's no trick: the crab is crushing the armor with a force that a crab could realistically generate. We also found that the crab usually starts eating at the head of the *Agonopsis*, which we will look into further in order to determine if this is a behavior that is replicable in the wild. While the armor of the *Agonopsis vulsa* does not offer protection from crushing crab claws, it may offer enough resistance to help increase the chance of survival in an initial interaction or protect from other factors in its environment.

P39-3 Tramonte, CA*; Wuitchik, DM; Aichelman, HE; Davies, SW; Department of Biology, Boston University, Boston, MA, USA; *tramonca@bc.com*

Can we rapidly assess algal symbiont densities in facultatively symbiotic corals using photographic assessments?

Corals are threatened worldwide due to rapidly warming oceans associated with anthropogenic climate change. Increasing temperatures can lead to coral bleaching, which is the loss of the obligatory symbiotic relationship between the coral host and their algal symbionts. However, some corals are facultatively symbiotic and can thrive both with and without symbionts. Facultative corals, therefore, offer an interesting model system for understanding the mechanisms governing coral bleaching, which is critical knowledge for protecting these ecosystem engineers under a changing world. Quantifying levels of symbiosis remains a challenge, and existing methods require the destruction of the coral in order to determine symbiont densities. Here, we develop a non-invasive image-based analysis of pigment density for two facultatively symbiotic corals, which naturally exist both as symbiotic and aposymbiotic colonies, which will help further develop these species as models for coral bleaching. Images of corals that varied in their symbiont densities were analyzed with ImageJ and algal densities were approximated via modified MATLAB scripts. Estimated algal densities were correlated with relative proportions of algal symbiont reads to total coral

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plus symbiont (holobiont) reads via tag-based RNA sequencing. Our photographic assessments of *Oculina arbuscula*, but not *Astrangia poculata*, correlated well with symbiont densities from RNAseq data, which suggests that although these image-based analyses can provide an accurate, rapid, and scalable assessment of algal symbiont densities, they must be further developed to specific species.

P32-6 Truesdell, CA*; Horton, BM; Robinson, KS; Hoover, JE; Millersville University, Millersville, PA; *john.hoover@millersville.edu*

Age-related changes in the performance of female C57BL/6J mice during a battery of behavioral tests

The objective of this study was to determine whether age affects the performance of female C57BL/6J mice during a battery of behavioral tests. Female C57BL/6J mice were subjected to three consecutive behavioral tests during young adulthood (2-3.5 months) and again at middle age (10-11 months). These tests were the elevated plus maze (EPM), open field test (OFT), and tail suspension test (TST), which are commonly used to assess anxiety-like, exploratory, and depression-like behaviors in mice. Each animal was randomly assigned to one of six groups (5-6 mice/group), where the sequence of the tests within the test battery was varied for each group. The performance of the animals in each test was video recorded and a number of behavioral parameters were measured, including the time spent on the open arms of the EPM, the number of grid squares crossed in the OFT, and immobility time in the TST. Statistical analyses were performed to examine the potential effects of age and group (i.e., test sequence) on behavior during these tests. The results demonstrated that the female mice exhibited more exploratory behavior when they were younger than when they were older. Furthermore, there was evidence that behavioral types (e.g., shy vs. bold) were persistent as the animals aged. An effect of test sequence on behavior was also observed, but this effect was limited to the performance of younger mice in the EPM. These findings suggest that the age of the animals and test sequence are important considerations when designing behavioral studies of mice.

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P39-7 Tsang, LC*; Aichelman, HE; Benson, BE; Davies, SW; Department of Biology, Boston University; *laurtsa@bu.edu*

Diel thermal variability structures algal and microbial symbiont communities in the reef-building coral, Siderastrea siderea

Coral resilience to thermal stress relies in part on the composition of their symbiotic community, which includes algal symbionts in the Family Symbiodiniaceae and members of the microbiome living within the coral host. Because corals are long-lived and sessile, modulating their symbiotic communities may play an important role in acclimatization to distinct environments. Corals living in environments with higher levels of diel thermal variability (DTV) have been shown to exhibit increased thermal tolerance; however, little is known about how DTV structures coral symbiont communities. In this study, three inshore and three offshore reef sites in Bocas del Toro, Panama that differ in their DTV were used to investigate the structure of symbiotic communities of the reef-building coral *Siderastrea siderea*. Metabarcoding of the ITS2 (algal) and 16S (microbial) loci allowed for comparison of community diversity and abundances of symbionts between inshore and offshore reefs, which differ in their DTV. We found abundances and composition of both ITS2 and 16S communities were significantly different between inshore and offshore reefs. Specifically, algae in the genus *Durusdinium* were found to be more prevalent in offshore populations while *Cladocopium* were more abundant inshore, suggesting that different levels of DTV experienced on these reefs might drive differences in the algal communities hosted by *S. siderea* in this region. Additionally, three bacterial indicator species were identified as potential biomarkers of thermal variability. We conclude that divergent DTV experienced on inshore and offshore reefs plays a role in structuring symbiotic communities of *S. siderea*.

P37-7 Turner , AM*; Reichard, DG; Schultz , EM; Davis, KM; Meehan, ME; Ohio Wesleyan University , Ohio Wesleyan University, Ohio Wesleyan University; *aturner5@illinois.edu*

Is mate switching an adaptive behavior in house wrens (Troglodytes aedon)?

The quality of an individual's mate directly affects fitness. When mate quality is poor, reproductive success can be low. Mate

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switching is a behavior that occurs in many avian species that may increase fitness in individuals initially paired with low-quality mates. This behavior occurs when a pair bond is severed, a new mate is found, and a new pair bond is formed. Mate switching is most commonly observed between breeding seasons, but multi-brooded house wrens (*Troglodytes aedon*) will frequently switch mates within a single breeding season between nesting attempts. Here, we studied mate switching behavior in house wrens to examine its potential adaptive value. We caught 82 male and female house wrens, and banded each individual with a unique color combination to identify them while observing pairing and parental care behavior. If mate switching is adaptive, individuals that switched mates should have higher fitness than the individuals that did not switch mates. However, consistent with previous studies, we found that pairs that switched mates did not have larger clutch sizes than pairs that stayed together for multiple nesting attempts. Despite the lack of effects on fitness, the majority of pairs in our population switched mates (81%). A high rate of nest failure (33%) may have contributed to frequent mate switching, but more years of data are needed to access this link. Future work should examine differences in offspring quality and mate compatibility as potential adaptive factors underlying mate switching in this species.

P23-4 Tutelo, GA*; Welch, AM; College of Charleston, SC; *tuteloga@g.cofc.edu*

Effects of transient salinity stress on larval growth and development in the southern toad (Anaxyrus terrestris)

Increasing salinity levels are an important threat to many freshwater ecosystems. In coastal freshwaters, transient increases in salinity can result from coastal flooding and storm surge, enhanced by climate change and rising sea levels. Phenotypic plasticity can enable organisms to respond adaptively to changing or unpredictable conditions, and many examples of plasticity involve shifts in developmental trajectories, including altered rates of growth and development. Amphibian larval development provides an excellent opportunity to study such developmental plasticity. In high quality environments, larval amphibians are predicted to reduce developmental rate in order to reach maximum size at metamorphosis, while in poor environments with slower

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growth, individuals are predicted to accelerate development in order to metamorphose as early as possible, resulting in smaller size at metamorphosis. When the quality of the environment changes during development, larval amphibians may be able to shift developmental trajectory, even accelerating growth rate enough to compensate for earlier growth suppression. In an experiment with toad tadpoles, we investigated plasticity in growth and development during and after exposure to elevated salinity during different portions of larval development. We predicted that growth rates would be more plastic early in development and that developmental plasticity would be constrained during both early and late developmental stages and thus apparent only during mid-development. In addition to providing insights into the capacity for adaptive developmental plasticity in larval amphibians, our results will also help evaluate potential impacts of salinity changes in freshwater habitats.

P25-12 Ulrich, M*; Ebert, D; Stillman, JH; University of Basel, University of Basel and San Francisco State University and University of California, Berkeley; *moena.ulrich@unibas.ch*
Exploring the relationships among metabolic rate, movement, thermal tolerance and life-history traits across diverse populations of the freshwater crustacean Daphnia magna
Physiological and life-history tradeoffs may result from local adaptation of populations across wide environmental gradients, and facilitate inferences of the ecological consequences of climate change. For example, local adaptation to warmer thermal habitats may increase heat tolerance to the detriment of metabolism, movement and lifetime fitness. Though theoretically accepted, there remains scant empirical evidence for tradeoffs from local adaptation to temperature. To assess the physiological link among physiological and life history traits, genotypes from > 200 populations of the freshwater crustacean *Daphnia magna* from across the northern hemisphere were used to measure oxygen consumption, swimming rates and life-history traits (body size, age and fecundity at maturation). Those phenotypes were then related to previously determined thermal tolerance levels for each genotype. Routine metabolic rates (RMR) were measured using PreSens SDR 1-ml vial respirometers, and routine swimming velocities (RSV) were

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measured using a video tracking system. RMR positively correlates to RSV, and both traits positively correlate to thermal tolerance, while they negatively correlate to body size. Fecundity and body size at maturation are positively correlated with age at maturity. Our results support the tradeoff hypothesis in that enhanced thermal tolerance is correlated with low fitness in life-history traits. Because our populations originate from a wide range of habitats (e.g. size of water body, elevation, climate, water chemistry, seasonal phenology) a broad range of conditions are represented, allowing for further inferences about local adaptation and the possible response to changing environments.

P23-9 Vandiest, IJ*; Lane, SJ; Sewall, KB; Virginia Tech, Blacksburg; *ivandiest@vt.edu*

Effects of urbanization on the nestling nutrition of song sparrows

Urbanization presents new challenges to organisms that persist in modified habitats. Urban environments can have reduced biodiversity, altered nutrient availability, and thus, species that persist in urban habitats may have access to less nutritious food or less food overall. Previous work has found that arthropod communities upon which many songbirds rely during breeding are of lower trophic levels in urban environments. A study in crows found that urban nestlings had lower plasma protein and calcium relative to rural nestlings. To determine how urbanization might impact food availability and nutritional quality for song sparrows, a common North American songbird found in both rural and urban habitats, we completed arthropod surveys 5 times during the breeding season and measured circulating whole protein and calcium levels from 64 urban and 25 rural nestlings across 3 rural and 3 urban sites. We found that our urban study sites had lower arthropod biomass, lower ratios of nutritionally rich orders (e.g. Aranae) and fewer arthropods overall compared to rural sites. Despite differences in arthropod communities we did not find differences in nestling plasma protein across habitats. Rather, protein increased with age ($p=0.0176$). Calcium was higher in urban areas ($p=0.0082$), but there was an inverse relationship between age and circulating calcium in urban habitats ($p=0.0123$) such that older nestlings had less calcium. These data suggest that urban habitats, though harboring fewer arthropods, may not be nutritionally limiting and that

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nestlings receive equal and presumably adequate nutrition in both habitats. Future studies will compare diet by measuring what parents are feeding young, and will consider other measures of nestling nutrition by measuring free fatty acids, glucose, and triglycerides.

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P25-8 Vazquez, OA*; Rahman, MS; University of Texas Rio Grande Valley; *omar.vazquezperez01@utrgv.edu*

Effects of heat stress on cellular stress response in the common goldfish, Carassius auratus

Abstract Due to global climate change, the aquatic organisms adapt to drastic temperature fluctuations and low dissolved oxygen levels in the freshwater ecosystem; however, the development of thermotolerance to extreme temperatures (32° C) and novel stresses (e.g. hypoxia) depends on a graded physiology and cellular stress response. In order to assess the effects of elevated temperature on cellular physiology, common goldfish (*Carassius auratus*) were purchased from local market and randomly assigned to six 20-gallon aquaria (20 fish/aquarium). All fish were acclimatized for 1-month (22° C) and exposed to control (22° C), medium (26° C), and high (32° C) temperatures for 4-week. After the experimental period, brain, liver, kidney, and gill tissues were collected and fixed in 4% paraformaldehyde. Basic parameters (e.g., condition factor, morphometry) were measured and the histological findings of gill, kidney, liver, and brain tissues were analyzed. Tissues from medium and high treatment groups (26 and 32° C) revealed cellular injury and necrotic cell death. The histological lesions of neuronal vacuolation and reduced glomerular diameter were found in brain and kidney tissues, respectively, at high treatment groups. Further studies for the confirmation of altered activity/expression of antioxidant enzymes (e.g., catalase, superoxide dismutase, and glutathione peroxidase), oxidative biomarkers (e.g., dinitrophenyl protein, nitrotyrosine protein, protein carbonyl content) and in situ TUNEL assay for cellular apoptosis will elucidate a mechanistic approach to the graded cellular stress response in goldfish.

P37-2 Vergun, MR*; Weinstein, J; Graves, H; McCabe, EA; Solomon-

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Quantity and quality of early-life social relationships affects behavior and neuroendocrine function in a highly social fish

Early-life environment is strongly implicated in the development of social behavior across species, yet fundamental questions remain about the underlying behavioral mechanisms. We studied the mechanisms of early-life behavior development in the highly social African cichlid fish, *Astatotilapia burtoni*. By manipulating the number and concurrence of social partners during early-life, we were able to rear juveniles that varied in the quantity and quality of their social experiences. Fish were reared in a stable pair (one social partner); a rotating pair (novel social partner every five days, five total partners); or a stable group (five social partners). We then tested the effect of early-life social environment on individual social behavior in a battery of behavioral assays, including for dominant and subordinate behavior. We found that both the total number of social partners and group size influenced behavior. Fish from the rotating pairs were significantly more interactive than stable pair fish in both dominant and subordinate contexts. Group-reared fish initiated intermediate rates of behavior and were approached more by subordinates when dominant. The hypothalamic-pituitary-interrenal axis is a highly conserved mediator of early-life experiences, and in juvenile *A. burtoni*, rearing environment affects the neural expression of stress axis genes. Therefore, we quantified water-borne cortisol levels to investigate treatment differences and interactions with social behavior. These results provide insight into how the quality and quantity of social experiences during early-life shape behavior and underlying mechanisms.

P19-10 Verheye, M.L*; Herrel, A; Frédérich, B; Castrec, C; Michel, L; Lepoint, G; MNHN, Paris, France and ULiège, Liège, Belgium, MNHN, Paris, France, ULiège, Liège, Belgium, Université de Bretagne Occidentale, Brest, France, Ifremer, Brest, France, ULiège, Liège, Belgium; *mverheye@uliege.be*

How mandible morphology relates to trophic ecology in Antarctic

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amphipods : the case of Iphimediidae revealed by 3D-Geometric Morphometrics and Stable Isotopes.

From about 40 mya, while Antarctica geographically isolated from the rest of the world, the marine shelf fauna faced a dramatic decrease in water temperatures. Many lineages went extinct, while others adapted and flourished. The Antarctic clade of the amphipod family Iphimediidae was among the successful ones. Ecological niches left vacant by the extinction of competitors might have led to the adaptive radiation of this clade. Antarctic iphimediids present a high interspecific variation in mandible morphology. These specific morphologies were previously examined in a few species which were interpreted as micropredatory browsers, each specializing on a preferred food prey. However, the relationship between mandible morphology and trophic niche remains poorly understood. Here, micro-computed tomography scans of the head region were performed in a range of iphimediid species. Geometric morphometric methods were used to obtain 3D shape data of the mandibular body. Secondly, stable isotope ratios (N, C) were measured as variables describing the trophic ecology of the species. By analyzing morphological variation in a phylogenetic context and assessing possible evolutionary correlations between mandible morphology and trophic ecology, we aimed to (i) evaluate adaptation hypotheses and (ii) inform on the eco-evolutionary causes of phenotypic change.

P18-6 Vidal-García, M*; O'Hanlon, JC; Svenson, JG; Umbers, KDL; Ecology and Evolution, Research School of Biology, Australian National University, Canberra, ACT 0200, Australia and Department of Cell Biology and Anatomy, University of Calgary, Calgary, Alberta, Canada, School of Environmental and Rural Science, University of New England, Armidale, New South Wales, Australia , Department of Invertebrate Zoology, Cleveland Museum of Natural History, Cleveland, OH, USA , School of Science, and Hawkesbury Institute for the Environment, Western Sydney University, Penrith, NSW 2751, Australia ; *marta.vidalga@gmail.com*

The evolution of startle displays: a case study in praying mantises

Anti-predator defences are typically regarded as relatively static signals that conceal prey or advertise their unprofitability.

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However, startle displays are complex performances that deter or confuse predators and can include a spectacular array of movements, colours and sounds. Yet, we do not fully understand the mechanisms by which they function, their evolutionary correlates, or the conditions under which they are performed and evolve. Here, we present the first phylogenetically controlled comparative analyses of startle displays including behavioural data, using praying mantises as a model system. We included 58 species that provide a good representation of mantis diversity and estimated the strength of phylogenetic signal in the presence and complexity of displays. We found that startle displays and morphological traits were phylogenetically conserved, whereas behavioural traits were highly labile. Surprisingly, body size was not correlated with display presence or complexity in phylogenetically controlled analyses. Species-rich clades were more likely to exhibit displays, suggesting that startle displays were probably involved in lineage diversification. We suggest that to further elucidate the conditions under which startle displays evolve, future work should include quantitative descriptions of multiple display components, habitat type, and predator communities.

P15-2 Vignos, AM*; Wilcoxen, TE; Millikin University ; *avignos@millikin.edu*

Cortisol level of redfin shiners (Notropis umbratilis) varies among riparian areas with different land use practices

Native habitats have been altered by human activity to create spaces for human use, such as urbanization and agriculture. These alterations often disrupt the natural landscape, resulting in habitat isolation, loss, and fragmentation. Creeks can be influenced by human development, and such development can impact many creek-dwelling species. Drastic changes in pH or dissolved oxygen can disrupt the creek biota, including alteration of fish assemblages and health. The purpose of this study was to determine if different riparian land alterations affect the water quality of various creeks and the physiology of creek-dwelling fish, using Redfin Shiners as a model species. Redfin Shiners were captured with a seining net at 12 different sites among 4 different creeks in Central Illinois. These sites could generally be classified as residential, agricultural, or riparian areas protected from

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development. We also recorded a suite of water chemistry data. We captured 271 Redfin Shiners among the sites, placing each into hormone-free spring water for 30 minutes, allowing them to exude cortisol and then measuring cortisol extracted from water samples. We found higher cortisol levels among fish in creeks with lower average dissolved oxygen over the 8-week study. Creek sites immediately downstream from agricultural areas had the lowest dissolved oxygen and shiners with the highest cortisol levels; whereas fish in the areas protected from development had the lowest cortisol levels. Our findings demonstrate that significant alteration of the stream habitat and associated changes in stream chemistry can impact glucocorticoid levels in native, pool-dwelling fish.

P26-1 Villatoro-Castañeda, M*; Forsburg, ZR; Fritts, SR; Gabor, CR; Carlos-Shanley, C; Texas State University; *melvcc@gmail.com*
Glyphosate and antibiotics reduce activity and affect growth in Rio Grande leopard frog (Rana berlandieri) tadpoles
Amphibians are the most endangered vertebrate taxa, facing population declines worldwide. Amphibians, as well as their microbiome, are highly susceptible to pollution associated with agriculture and urbanization land use conversion. Glyphosate, the most widely used herbicide in the US, is an immunosuppressant, increasing species vulnerability to infectious diseases and pathogens. A direct relationship between the gut microbiome, digestive, immune, metabolic, and neurobehavioral processes exists. Disturbances of the gut microbiome leads to health disruption. We explored the effects of glyphosate and antibiotics in the growth and behavior of *Rana berlandieri* tadpoles. We quantified the gut microbiome bacterial diversity of tadpoles reared in one of four treatments: (1) an environmentally relevant, but non-lethal, concentration of glyphosate, (2) an antibiotic cocktail to excise tadpoles of their natural microbiome, (3) both glyphosate and antibiotics (combination), and (4) a control group. We also measured growth every 3 days. After 11 days we quantified activity and after 14 days we collected the gut from 2 tadpoles per tank. The remaining tadpoles were moved to untreated water and reared for 2 months to measure recovery. Tadpoles in the combination and antibiotic treatments had lower growth compared to control

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tadpoles. Control tadpoles were more active than tadpoles in other treatments. After recovery, glyphosate exposed tadpoles grew larger than control tadpoles. Behavior results indicate that tadpoles exposed to glyphosate become lethargic. A disturbed microbiome results in lower growth rates, lethargy, and delayed development. Glyphosate use should be avoided to maintain a healthy microbiome, especially when tadpoles are developing.

P8-5 Vincent, BA*; Lau, ES; Ramamurthy, SV; Oakley, TH; University of California, Santa Barbara; *bridget.vincent@lifesci.ucsb.edu*

Cephalopod photophores: Estimating the origins of complex convergent traits

Convergent traits arise when distantly-related taxa independently develop similar phenotypes. However, the origins of these traits can be difficult to estimate, especially in complex traits which are not governed by a single gene. Determining where these traits originate is key in understanding their evolutionary history and how patterns of convergence persist in multiple levels of biological organization. Bioluminescence is a convergent, complex trait present across taxa in both marine and terrestrial species, including the class Cephalopoda. The organ producing bioluminescence (photophores) shows extensive morphological diversity across both taxa and biological levels. Different species of cephalopods may have bacteriogenic photophores (organs whose symbiotic bacteria produce light) or autogenic photophores (organs that produce light using their own cells) in varying degrees of complexity. Though we know cephalopod bioluminescence is convergent, the number of independent origins of these complex traits is a mystery. We performed parsimony-based ancestral state reconstruction on a previously published genus-level cephalopod phylogeny and found at least 10 origins of cephalopod photophores (3 bacteriogenic and 7 autogenic). Ongoing work includes building a species-level phylogeny using published short-read genetic data, transcriptomes, and genomes to assess whether a higher resolution affects our estimates of evolutionary origins. Additionally, we are gathering morphological data for each species' photophore to perform ancestral state reconstruction on cellular and tissue-level characters. This will allow us to determine if patterns of

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convergence remain consistent across biological levels in a complex trait.

P3-6 Wallace, KJ*; York, JM; The University of Texas at Austin; *kwallace@utexas.edu*

A systems change framework for evaluating academic equity and inclusion in an ecology and evolution graduate program

While academia is moving forward in terms of diversifying recruitment of undergraduate and graduate students, diverse representation is still not found across the academic hierarchy. At the graduate level, new discussions are emerging around efforts to improve the experiences of women and underrepresented minorities through inclusive graduate programming. Inclusive graduate programs actively center and prioritize support for diverse experiences, identities, career goals, and perspectives, from recruitment through graduation. Establishing regular and rigorous evaluation of equity and inclusion efforts and needs is a critical component of this work. This is recognized by funding agencies that increasingly require reporting on inclusion efforts; here we suggest use of a systems change framework for these evaluations. A systems change approach emphasizes three levels: explicit change (e.g. policies), semi- explicit change (e.g. power dynamics), and implicit change (e.g. biases). We argue this framework is particularly useful for academic systems as they are complex, composed of variable individuals, and must address diverse stakeholder needs. We use the Ecology, Evolution, and Behavior (EEB) PhD Program at the University of Texas at Austin in an exercise to (1) identify areas of concern regarding inclusive programming voiced by graduate students, (2) categorize efforts to address these concerns, and (3) integrating and evaluating which areas of the systems change framework show the greatest progress or potential for progress.

P37-4 Wang, JY*; Paggeot, LX; Friesen, CN; Solomon-Lane, TK; Hofmann, HA; Young, RL; The University of Texas at Austin; *joyce.wang@utexas.edu*

The neural transcriptomic basis of attaining social dominance status

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Group-living animals nimbly respond to social challenges and opportunities by changing hormone profiles, neural activity patterns, and gene expression. How these processes are integrated into context-appropriate changes of behavior is not well understood. In vertebrates, this complex process depends on the distributed activity of a highly interconnected and conserved set of fore- and midbrain regions known as the social decision making network (SDMN). Here, we use the highly social African cichlid fish *Astatotilapia burtoni*, a model system in social neuroscience, to characterize the neural transcriptomic response to a social opportunity. We provided subordinate males an opportunity to ascend to dominant status for up to 1 week and quantified behavior and physiology at three time points after the onset of social ascension, followed by an analysis of transcriptomic response of three critical SDMN nodes (homologs of the preoptic area, hippocampus, and extended medial amygdala). We first replicate that behavioral and physiological changes that have previously been shown to accompany social ascent. We then find that the three SDMN nodes we investigated have distinct transcriptomic profiles that change in subtle ways as animals ascend in social status. Finally, we uncover genes and gene co-expression modules that are associated with behavioral and physiological measures, suggesting specific molecular pathways that allow ascending males to take advantage of social opportunity. Taken together, our results provide insight into the neuromolecular changes occurring throughout the process of social ascent.

P25-7 Wang, W*; Gunderson , A; Tulane university ; *wwang16@tulane.edu*

Effect of temperature on sperm motility and longevity in Anolis sagrei

To examine the ecological and evolutionary impact of global climate change on animals, many studies have assessed the relationship between temperature and performance of the diploid (usually adult) stage. Fewer studies have focused on how high temperature could reduce reproductive success by effecting gamete performance. In this study, we tested for impacts of warm temperatures on sperm of the brown anole, *Anolis sagrei*. We measured sperm motility after sperm were exposed to temperatures from 28 to 50° C for 2 to 60

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minutes. We found that both temperature and time affected sperm motility, with the sharpest declines after exposure to 43.9 ° C or higher. To elucidate the effect of mild but longer-term heat, we separated sperm samples into 2 groups exposed to 28 or 33° C for 24 hours. We found that sperm motility decreased significantly more in the 33 ° C compare to the 28 ° C treatment. Overall, our result suggest that both sperm longevity and motility are highly effected by temperature and further study is required to elucidate the effect of warmer temperature on overall fertility.

P6-1 Warfield, J*; Dalal, A; Hill, R; Kaiser, SA; Lohr, B; University of Maryland Baltimore County, Laboratory of Ornithology, Cornell University; *blohr@umbc.edu*

Song variation and diversity in grasshopper sparrows of the Caribbean

Divergence across island populations in a region can occur rapidly when signals, such as the learned songs of birds, act as behavioral barriers to gene flow. We conducted a comparison of male songs in grasshopper sparrows (*Ammodramus savannarum*) across several island populations in the Caribbean, including Jamaica (*A. s. savannarum*) and Bonaire/Curacao (*A. s. caribaeus*). Grasshopper sparrow males sing two distinct songs: an insect-like "buzz" song and a "warble" song. Birds also sing a combination song (buzz followed by warble) when transitioning between these songs. Buzz songs in the Caribbean consisted of one or two brief introductory notes followed by a longer, rapidly-modulated sequence of very brief notes or note complexes, followed by a final short note. By analyzing the spectral and temporal components of buzz songs, we determined how songs varied across and within islands. We were able to distinguish key differences between songs and singing patterns based on geographical origin. Each Caribbean subspecies has a typical buzz song type (although *A. s. savannarum* has two) and songs are individually distinctive. *A. s. caribaeus* (the rarest subspecies studied) have the most distinct songs. Their songs showed the most rapid modulation rate, the least inter-individual variation, and these birds sang the combination song type almost exclusively. Our findings reveal distinctive differences in song structure across the Caribbean islands, and future work will

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compare these Caribbean songs to the songs of several grasshopper sparrow subspecies on mainland North America.

P19-8 Watanabe, J; University of Cambridge, Cambridge, UK; *jw2098@cam.ac.uk*

Quantifying evolutionary bias from character covariation: simulation-based approach for (evolutionary) covariance matrices

The extent to which certain phenotypes are more likely to be attained than others (evolutionary "bias") is among the central questions in evolutionary biology. Character covariation plays a pivotal role in quantitative investigations on evolutionary bias, and dispersion (variance) of eigenvalues of a covariance matrix, standardized to the number of variables, is often used as a measure of bias. However, sampling properties of this measure are not well known, complicated by the fact that eigenvalues are not stochastically independent of one another in a sample covariance matrix. Here, sampling properties of the dispersion of eigenvalues of a covariance matrix are investigated with simulations of i.i.d. or Brownian-motion-based normal samples for a range of moderately low p/n (number of variables / sample size) ratio, and a simple framework is proposed for detecting evolutionary bias from comparative datasets. Simulations showed that, as expected, the dispersion measure tends to be overestimated, especially when its population value is small. The upward estimation bias decreased markedly with increasing n, but did not vary prominently with p in the conditions examined. The (apparent) precision increased with increasing n and p. For empirical cases, observed values of the dispersion measure can be compared with parametric bootstrapping and Monte Carlo null distributions to assess estimation bias and to test hypothesis of no evolutionary bias, respectively. When dealing with comparative datasets, phylogenetic generalized least squares-based estimation of covariance was found to be by far superior to the non-phylogenetic counterpart, at least in idealistic situations where the true tree is known and assumed evolutionary model is correct. Influence of stabilizing selection and high p/n ratio should be investigated in the future.

P28-1 Weeger, A*; Lavrov, D; Iowa State

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Mitochondrial introns of Porifera: Implications of a greater prevalence

While the mitochondrial genome has been extensively studied since its discovery, the presence of mitochondrial introns in animals wasn't confirmed until 1982. Further, they were generally thought to be absent from non-bilaterian lineages until 1996. Mitochondrial introns are still poorly studied in non-bilaterian lineages, leading to an incomplete understanding of their actual diversity. After sequencing, we have identified 17 previously undescribed introns within the *cox1* gene, across 7 clades of phylum Porifera (sponges). Four of these clades have not previously been known to contain introns. Of the 17 identified introns, 14 are of type I and three of type II. Previous studies had only reported a single instance of a type II intron in Porifera. We propose that these and previously reported introns arose from Horizontal Gene Transfer (HGT) events from ancestral algae species into Porifera. We also report on the first instance of an intron in the *cox2* gene of animals. This intron is of type II and is distinct from type II introns found in *cox1*, which leads us to believe it has arisen from an independent HGT. This study more than doubles the number of species known to contain introns in Porifera and shows that our understanding of intron distribution is still incomplete. Further study of previously under-sampled species is the only way to gain a more complete understanding of this genomic element.

P27-1 Weitzman, CL*; Salcido, D; Muchoney, N; Yoon, S; Espeset, A; Larsen, E; Lindauer, A; Slinn, H; Voyles, J; Smilanich, AM; Virginia Tech, University of Nevada, Reno, University of Guelph; *clweitzman@vt.edu*

Testing the metabolic pace-of-life model among vertebrate immune responses

The study of ecological immunology provides a framework for investigating interactions that influence the strength and nature of animal immune responses. Costs associated with mounting immune responses presumably lead to trade-offs with other physiological processes (e.g., reproduction), but inherent to these factors is the organism's pace of life. Two papers published in ICB, Lee (2006) and Sandmeier and Tracy (2014), present hypotheses on the

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ways in which vertebrate pace of life should predict immunological investment in innate vs. adaptive, and constitutive vs. induced, immune responses. Specifically, "slow-living" (long-lived, slow-growing) species are predicted to invest more in induced, adaptive immunity. Investment into these costly immune responses prioritizes survival to enable future reproduction, but also prepares the host for repeated exposure to a pathogen with immune memory enabled by the adaptive immune response. In contrast, "fast-living" (short-lived) species are quick to reproduce and are predicted to rely more on constitutive, innate (non-specific) immunity. In this study, we took a quantitative approach to testing the ecoimmunological pace of life model. With a meta-analysis of over 300 effect sizes from peer-reviewed literature of vertebrate immune responses to parasites, pathogens, and artificial stimuli, we assessed the generality of predictions surrounding life-pace and immune responses. Using longevity as a metric of pace of life, we found that immune responses follow predictions of immune investment in some taxa and not others. We use these data to address differences in immune responses between endotherms and ectotherms, as well as tropical vs. temperate species.

P39-9 White, ER*; Weis, VM; Oregon State University; *whitee3@oregonstate.edu*

Characterizing the role of nutrient transporters in development and symbiosis establishment in Exaiptasia diaphana

In a time when corals are facing massive mortality events, it is crucial to gain an understanding of the underlying symbioses between corals and their algal symbionts. The sea anemone Exaiptasia diaphana, commonly known as Aiptasia, has been widely used as a model system for understanding the cnidarian-dinoflagellate symbiosis because it can be maintained easily in a lab, it engages in a symbiosis and can be colonized with different algal species, and it can be maintained in an aposymbiotic state. In addition, Aiptasia undergoes a rapid form of asexual reproduction called pedal laceration, during which anemones leave behind a piece of the symbiotic pedal disk that will develop into a juvenile polyp. Laceration presents itself as a novel way to study the process of symbiosis establishment during host development. During juvenile polyp development, symbionts invade the developing

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tissue ultimately resulting in a fully symbiotic juvenile. The purpose of these experiments was to test expression of nutrient transporters as markers for symbiosis establishment during host development. We focused on the glucose transporters GLUT8, HMIT, and SMIT and lipids as markers for energetics by using fluorescence and bright field microscopy. We compared localization and abundance of glucose transporters and lipids in symbiotic vs aposymbiotic lacerates and tracked expression through time in symbiotic lacerates as they developed into juvenile polyps. Glucose transporters were detected with polyclonal antibodies against transporter proteins, and Oil Red O and BODIPY stains were used to visualize lipids in host tissues. Findings from these experiments will be crucial in furthering our understanding of animal development and symbiosis establishment in cnidarians.

P19-2 Williams, KL*; Hundt, PJ; Keogh, SM; Simons, AM; Clemson University, University of Minnesota; *keiffew@clemson.edu*
Re-thinking modes of teleost tooth replacement using the dentally diverse combtooth blennies (Blenniidae)
Teleost tooth replacement is historically categorized into two discrete modes: replacement occurring in soft tissue outside the dentigerous bone (extraosseous) or within dentigerous bone (intraosseous). However, increasing evidence suggests more complexity. Extraosseous is considered the plesiomorphic state in teleosts and intraosseous derived, although there appear to be reversals to the plesiomorphic state in some taxa. The combtooth blennies are characterized by a heterodont dentition consisting of a single row of anteriorly positioned feeding teeth and posteriorly located canines that can be present on both the upper and lower jaws. However, no studies have investigated canine replacement or its relation to feeding tooth replacement in blennies. We used methods including histology, clearing & staining, and micro-CT to explore the question: Is canine replacement developmentally distinct from feeding tooth replacement in blennies? We found that canines are always replaced intraosseously, while feeding teeth range across taxa from extra- to intraosseous replacement. Following the observation of taxa that simultaneously possess intraosseous canine replacement and extraosseous feeding tooth replacement, we hypothesize that extraosseous replacement is

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derived from intraosseous replacement in blennies. Preliminary results from phylogenetic comparative analyses support our hypothesis, indicating that many blennies possess a derived extraosseous replacement mode. Teleost tooth replacement is far more complex than current categories suggest. Re-thinking categorizations to be inclusive of taxa with complex dentitions may provide valuable insight into processes related to the evolution of trophic morphological novelties in teleost fishes.

P36-5 Williams, BA*; Brandon, CS; Florida Southern College , Florida Southern College; *brandonwilliams0814@yahoo.com*
The effects of chemical cues from a visually-guided predator, Gambusia affinis, on eye size development in Daphnia
The eye is a complex organ that plays a key role in how an animal perceives and responds to its environment. Eye size, in particular, is a large determinant of an animal's visual capabilities, where visual capabilities tend to improve with increasing eye size. Many studies have shown that eye size correlates with habitat and behavior across multiple taxonomic groups. Recently, a few studies have also demonstrated that visually-guided predators may target a conspicuously pigmented eye, thus constraining eye size in some species. To better understand the role of visually-guided predation in shaping eye size we evaluate phenotypic plasticity in a small freshwater crustacean, *Daphnia*. Here, we tested the "visual target hypothesis" which predicts that the eye size of a *Daphnia* exposed to predation cues will be significantly smaller than *Daphnia* exposed to no predation cues. This study was performed by exposing four species of *Daphnia* with chemical cues from *Gambusia affinis* or no chemical cues. Eye diameter and body length measurements were taken throughout the study in order to calculate relative eye sizes. Our results showed that relative eye size was not affected by the predatory cues, but absolute body size was. Therefore, the visual target hypothesis was not supported in our study.

P31-3 Wills, M*; Johnson, M; Brunmeier, E; Murphy, T; Johnson, T; Knights, D; Clayton, JB; Shields-Cutler, RR; Department of Biology, Macalester College, St Paul, MN , Como Zoo and Conservatory, St

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Paul, MN, Department of Veterinary and Biomedical Sciences, University of Minnesota, Saint Paul, MN, BioTechnology Institute, University of Minnesota, Minneapolis, MN, Department of Biology, University of Nebraska Omaha, Omaha, NE; *mwills@macalester.edu*

Captivity converges the microbiomes of diverse primate species

While links between environmental factors, gut microbiome composition, and host health have been well documented, details of these relationships remain unclear. By analyzing fecal samples from a diverse set of captive non-human primates (NHPs) from a single zoo, we aimed to further explore the ways in which captivity influences the NHP gut microbiome. All samples were processed using both "open" and "closed reference" pipelines. Open reference analysis used DADA2 *de novo* ASV clustering and both the SILVA and Greengenes databases, while closed reference analysis used only the Greengenes database. Both pipelines returned highly similar results, indicating that they could both be valid ways to process this type of microbiome data, and further supporting our conclusions. Using both methods, we found that within the sampled captive individuals, host species was the clearest driver of microbiome composition. However, when comparing captive and wild individuals from similar species, captivity status had a greater influence on microbiome composition than host species. Additionally, historic antibiotic usage was linked to a pattern of decreased alpha diversity and community evenness in captive emperor tamarins (*Saguinus imperator*), the species with the most sampled captive individuals. While this study provides novel insights into the gut microbiomes of diverse NHP species, work is ongoing to further investigate the specific impact of individual factors.

P17-10 Wojtas, H*; Davoll, M; Braasch, I; Thompson, AW; Michigan State University, Clemson University; *wojtasha@msu.edu*

Evolution of hatching gland and hatching enzymes in annual killifishes

Animals develop as embryos inside eggs and must hatch to allow the organism's free-living stage to begin. Aquatic vertebrate embryos typically hatch using their hatching gland. Hatching gland cells produce hatching enzymes that digest the chorion, the egg envelope protecting embryos from the environment. Killifish are a group of teleost freshwater fishes in the Cyprinodontiformes order. Annual

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killifishes inhabit seasonal freshwater pools in tropical region that periodically dry up so the adult population dies. Before the dry season, killifish spawn eggs in soil where embryos tolerate long periods of desiccation. Embryos enter different phases of arrested development, or diapauses, and require environmental cues like flooding to trigger hatching from final diapause stage. In teleost fishes, hatching enzyme genes have duplicated and sub-functionalized, resulting typically in two types, *high choriolytic-like enzyme* (*hce*), and *low choriolytic-like enzyme* (*lce*) genes. Both genes are highly dynamic with extensive copy number variation between species. Hatching enzyme repertoire and hatching gland location has thus far been unknown in annual killifishes. We infer the evolutionary history of killifish hatching enzyme genes in multiple species and investigate hatching gland morphology of annual Rio pearlfish (*Nematolebias whitei*), our central killifish model species. We show *lce* genes are expressed in the pharyngeal and buccal cavities, consistent with closely related species. Also, we describe a common trend of increased number of *hce* genes in killifish compared to *lce* genes. We aim to better understand how environmental cues induce hatching by studying and comparing spatiotemporal expression of hatching enzyme genes in killifish to other aquatic vertebrates and their evolutionary history.

P16-2 Wooding, AP*; Kline, BC; Christensen, KR; Keeley, ER; Pradhan, DS; Idaho State University; *woodale5@isu.edu*
Stress in a dynamic environment: How a cold water fish might cope with climate change
Poikilothermic organisms are susceptible to extreme variations in body temperature as their environment changes around them. When organisms experience chronically stressful environments, they may have to alter biological pathways to maintain homeostasis. Energetically costly responses can lead to allostatic overload and impact life functions such as growth, reproduction, and immunity. Cortisol is the major corticosteroid secreted by teleost fishes, and is a key mediator of stress-associated responses. While there has been extensive research on the physiological stress response in fishes in laboratory settings, information on how fish respond to stress in the wild is rare. Redband trout (*Oncorhynchus mykiss gairdnerii*) are a cold-water species that have adapted to persist

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in the thermally stressful environments of arid desert streams. Here, we investigate the stress response and subsequent effects on growth and size demography of wild redband trout in desert and montane ecosystems. We captured trout at 2+ years of age from 5 streams of differing temperature regimes at monthly intervals from June through October. We will measure concentrations of circulating cortisol, and relate it to habitat and morphometric data. We predict 1) there will be a seasonal variation in circulating cortisol levels associated with increased water temperature and 2) desert living fish will have adapted to the extreme environment and thus exhibit similar patterns of body size and demography as montane fish. These data will inform conservationists about the mechanisms by which organisms can adapt to the threat of increasingly warm waters associated with climatic change.

P8-6 Woodworth, B*; Fregosi, L; Suplicz, S; Palmeri, J; Gerringer, ME; State University of New York at Geneseo; *gerringer@geneseo.edu*
Classification of unknown deep-sea snailfishes through morphological and genetic evidence
The deep oceans make up more than 70% of the habitable biosphere on Earth, yet deep-sea environments remain largely unexplored. Snailfishes (Family Liparidae) live in cold and temperate ocean waters from the intertidal zone to more than 8,000 m deep sea and represent an important radiation into the deep oceans. Snailfishes share morphological characteristics including scaleless, tadpole-like bodies and commonly a ventral suction disk, yet they can vary by environment. Although more than 400 snailfishes have been described, the true diversity of and phylogenetic relationships within this widely distributed group remains unresolved. In this study, we focus on three deep-sea snailfishes that were caught in the Eastern Pacific Ocean off California. Using micro-CT (microcomputed tomography) scans, physical measurements, and meristics, we compared defining taxonomic characteristics such as body ratios and fin ray counts to the published literature. Morphologically, these individuals likely represent new species. Future analysis will include sequencing barcode genes (16S, COI, and Cyt-b) to position these species in a phylogenetic context. By comparing the morphological and genetic data from our unknown

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snailfish species to known taxa, we seek to further understanding of the vast biodiversity in our oceans.

P17-3 Xu, S*; Zhang, P; Jacobs, DK; University of California, Los Angeles; *sue_x17@yahoo.com*

Brachyury evolution and expression in the moon jellyfish Aurelia

The *Brachyury* subfamily of transcription factors plays key roles in animal development, but their expression and function vary between taxa. Studies have shown that *Brachyury* specifies the mesoderm in vertebrates, while others suggested that it regulates blastopore and endoderm-ectoderm demarcation in some Cnidarian species (*Hydra*, corals, etc.). It also functions in the growth zone where terminal addition of serial elements such as segments is the ancestral condition in Bilateria. However, no study has been done to investigate its role in the formation of the free-swimming medusa stage of Medusozoa, such as jellyfish. In this study, we focus on phylogenetic analysis of the gene *BracB*, a member of the *Brachyury* subfamily in the moon jellyfish *Aurelia coerulia*, and use *in situ* hybridization to examine its expression pattern in the medusa formation process called strobilation. During strobilation, polyps undergo body "segmentation", and each segment generates a single juvenile medusa. Our phylogenetic analysis suggests a duplication of *Brachyury* before the hydrozoa-scyphozoa divergence and groups the *Aurelia Bracb* with other medusozoan *Bra2* genes. However, a second copy of *Brachyury* is not found in anthozoans or staurozoans. Our preliminary *in situ* hybridization suggests that *BracB* expression is endodermal in late strobila. We also find that *BracB* expression is in stripes concentrated towards the younger segments of the strobila. Our data provides the first expression profile of *Brachyury* in medusa formation, shedding some light on the role of *Brachyury* in medusa body plan patterning.

P7-10 Yang, S*; Dao, A; Nyugen-Phuoc, K; He, Y; Waldrop, LD; Chapman University, University of North Texas; *waldrop@chapman.edu*

Odor capture by hair arrays in multiple configurations

Olfaction, the sensing of chemical cues, is a key task for most animals. A variety of crustaceans, including marine crustaceans and insects, gather chemical cues by moving external chemosensory hair

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arrays through environmental fluids. These arrays come in a vast diversity of morphologies and interact with a large number of odorants. Many of these hair arrays are dense, providing a large odor-capture surface area to detect rare odorants. However, the outer hairs of a dense array shields inner hairs from fluid containing odorants. Does the density of the array help to detect rare/dilute odorant signals? And does the fluid or speed of movement matter in detection? We constructed a variety of different hair arrays using a computational fluid dynamics model, varying in hair number and arrangement and simulated odor capture in a range of fluid properties and odorant diffusion coefficients. We found differences between hair array configurations in terms of shear flow around hairs and the overall leakiness on the array, and these depend heavily on the Reynolds number of the array. Odor capture varied with each array, and more sensory surface area did not result in higher levels of odorant captured, but varied with odorant diffusion coefficient and specific configuration. These results could help to describe the performance of hair arrays with common versus rare target odorants.

P20-2 Yap, KN*; Wong, HS; Ramanathan, C; Rodriguez-Wagner, CA; Freeman, DA; Zhang, Y; Auburn University, Calico Life Sciences LLC, University of Memphis, University of Memphis; *kny0004@auburn.edu*
Rate of living theory re-visited: mitochondrial, cellular, and whole-organism metabolism in Siberian hamster and the long-lived Damaraland mole rat
Biologists have long been interested in the physiological mechanisms that mediate longevity in animals. One of the theories regarding aging and longevity in animals is Raymond Pearl's rate of living theory, which postulates that heightened level of metabolism leads to an increased rate of aging and reduced lifespan in animals. The theory has received ample support from studies in ectotherms, but it is widely challenged in endotherms. The Damaraland mole rat (DMR; *Fukomys damarensis*) is a long-lived eusocial mammal. They can live in captivity for more than 20 years. They maintain stable body composition and only show slight age-related changes in physiological and morphological characteristics. Conversely, the Siberian hamster (SH; *Phodopus sungorus*) exhibits longevity typical of other rodents. We capitalized on these unique

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animal models and re-visited the rate of living theory by comparing bioenergetics of DMR and SH at the mitochondrial, cellular, and organismal levels. Preliminary analysis showed that both mitochondrial and cellular respirations were lower in DMR compared to SH. Basal metabolic rate (BMR) was also lower in DMR compared to SH. Additionally, BMR was not different between DMR of different ages. These findings support the rate of living theory and suggested that the extreme longevity of DMR could be attributed to their low metabolic rate. Data on other bioenergetics measurements from both species will be presented at the meeting.

P8-4 Yap-Chiongco, MK*; Kocot, KM; University of Alabama, Alabama Museum of Natural History; *mkyapchiongco@crimson.ua.edu*

Proteomic and developmental studies of aplacophoran sclerites to study the origins of molluscan mineralized structures

Molluscs are the second most diverse animal phylum. Their success in terrestrial, marine, and freshwater environments can be partially attributed to their ability to secrete a variety of biomineralized structures in the forms of shells and sclerites. Sclerites are calcium carbonate scales and spicules found in the clade Aculifera (Polyplacophora and Aplacophora). The homology of sclerites to shells in other molluscs (Conchifera) is unknown. Transcriptomic and proteomic approaches have provided insight into the genes and proteins responsible for patterning the shells of conchiferan molluscs. With no studies addressing biomineralization within Aplacophora, investigation into the proteome and development of sclerites is needed in order to make inferences about the evolutionary origins of dermal mineralized structures within Mollusca. In order to investigate the proteins involved in aplacophoran mineralization, sclerites will be collected from large-bodied species for shotgun proteomics using high performance liquid chromatography and MALDI-TOF mass spectrometry. This work will be the first proteomic analysis of aplacophoran sclerites, allowing us to make comparisons to what is known of the proteome of conchiferan shells. Additionally, *in situ* hybridization will be conducted in the solenogaster species *Wirenia argentea* in order to observe expression patters of genes encoding proteins of interest in the developing larvae. We will investigate genes with interesting properties that are identified in our proteomic work as

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well as genes known to be expressed during shell development such as *engrailed*, *pif*, *hox1*. This work will shed light on the formation of sclerites and their homology to conchiferan shells.

P16-3 Young, GK*; Gesquiere, L; Alberts, SC; Duke University, Durham, NC; *gkyoung777@gmail.com*

rainfall and puberty status predict energy balance in Amboseli baboons

Social-living primates experience changes in their physical and social environments throughout their lives. Sometimes-extreme environmental changes lead to fluctuations in food availability and influence the nature of social interactions, changing primates' energy intake and expenditure on daily and life-long bases. Growth and development before and during puberty creates additional energy demands. Balancing energetic demands of environmental fluctuations and growth with energy available for intake is essential for survival. Using triiodythyronine (T3) concentrations in baboons as a measure of energy balance, this paper seeks to quantify energetic balance from infancy to adolescence, and to analyze which environmental factors best predict T3 concentrations. First, I characterize longitudinal patterns of variation in T3 concentrations both in males and in females. Second, results from model selection show the strong predictive negative effect of sexual maturation and positive effect of cumulative rainfall on T3 concentrations. My results present patterning of T3 concentrations throughout infancy and adolescence and demonstrate how environmental factors and the important transition to adolescence affect the energetic balance necessary for survival. These findings provide a jumping off point for comparison of longitudinal patterning of hormone concentrations during development and open the door for further explorations of energetic balance during puberty.

P39-12 Zarate, MA*; Shanee, S; Schmitt, CA; Boston University , Neotropical Primate Conservation, Boston University; *mazarate@bu.edu*

Predicting suitable habitat for the critically endangered yellow-tailed woolly monkey (Lagothrix flavicauda) in Peru

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The Tropical Andes Biodiversity Hotspot holds a remarkable amount of species at risk of extinction due to climate change and human activities. The Critically Endangered yellow-tailed woolly monkey (Lagothrix flavicauda), has experienced revisions in its known geographical range in recent years, along with a recent sighting in the region Junín, 206 kilometers south of previous observations. In this study, we used a generalized linear modelling approach across and beyond the species' current range, incorporating ecological factors as predictor variables to species presence to estimate suitable habitat where the species may be living. The model incorporated 59 published localities and 517 randomly generated pseudoabsences. Precipitation most strongly predicted species presence in and our evaluation measures showed the model accuracy to be sufficiently accurate. Habitat suitability maps illustrate novel areas of potential corridors in central Huánuco and Pasco, though the latter region may be experiencing some degree of competitive exclusion with other primates. An analysis of the current protected area (PA) network in Perú revealed that around 80% of suitable habitat is unprotected from human development. Areas of suitable habitat should be surveyed to decrease bias in occurrence data, increasing the accuracy of habitat modelling for this species. Surveying these areas will also reveal corridors of gene flow between these populations, and could predict the best placement of PAs. Better characterization of the true distribution of the species will provide information to conservation practitioners in priority areas, helping to protect this species and associated threatened wildlife.

P9-3 Zhang, P*; Rozbu, M; Jacobs, D; University of California, Los Angeles, Asian University for Women; *pzhang312@ucla.edu*

A comparative study on transposable elements in the genus aurelia

Transposable elements have been shown to play a role in genome evolution and contribute to genome size expansion. The Scyphozoan jellyfish *Aurelia* genus is comprised of a number of species, including *Aurelia aurita*, and *Aurelia coerulia* (previously *Aurelia sp. 1*). Interestingly, the genome of *A. coerulia* is almost twice as big as that of *A. aurita*. In this study, we investigate whether this genome size difference is due to expansion of certain transposable elements.

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P36-3 Zino, RA*; Peele, EE; Yopak, KE; University of North Carolina at Wilmington; *raz8626@uncw.edu*

Effects of temperature on peripheral nervous system development in cartilaginous fishes

Sea surface temperatures have warmed by 0.5°C within the last century and are predicted to rise 1-4°C by the year 2100. These environmental changes become particularly concerning for ectothermic vertebrates, where metabolic rate is largely determined by environmental temperature. However, very little is known about how elevated temperature will affect the development of metabolically costly tissue, such as the nervous system. Elasmobranchs (sharks, skates and rays) occupy nearly every aquatic niche and play a key role in ecosystem structure and function. They also exhibit ontogenetic shifts, or changes in habitat, diet, or morphology, over the entire lifespan of an individual. Correspondingly, there are ontogenetic shifts in the relative development of sensory systems (e.g. visual, olfactory) and patterns of brain organization, potentially reflecting shifts in sensory specialization at key life history stages. However, to date, little is known about how normal development of the nervous system may be altered in response to an increase in environmental temperature. Using magnetic resonance imaging (MRI), this study compared the relative size of the eyes and olfactory rosettes in three representative species of cartilaginous fishes reared in ambient or elevated temperatures (3°C - 5°C): the little skate, Leucoraja erinacea, the port Jackson shark, Heterodontus portusjacksoni, and the epaulette shark, Hemiscyllium ocellatum. Trends indicate a difference in size of peripheral structures between treatment groups, which we hypothesize may reflect a decrease in metabolic efficiency at higher temperatures. Understanding effects of environmental temperature on the peripheral nervous system can have important implications for how changing ocean conditions may affect sensory capabilities, and thus longevity of these critical species.

P2-1 Zuelow, AN*; Burnaford, JL; California State University, Fullerton; *anz1@csu.fullerton.edu*

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Impacts of Egregia menziesii, a foundational alga, on intertidal communities in S. California and N. Washington

Canopy-forming seaweeds provide shade for smaller algae and invertebrates in intertidal communities, ameliorating low tide abiotic stressors such as ultraviolet radiation, desiccation, and high temperatures. Conversely, canopies can negatively affect understory organisms by limiting settlement, causing physical disruption, and trapping sand. We are examining the effect of *Egregia menziesii*, a canopy-forming foundation species, on intertidal communities, using manipulative experiments in two portions of its geographic range (southern California and northern Washington). We hypothesized that plots with *Egregia* would have higher abundance and richness of other invertebrates and algae than plots without *Egregia*. At each site, we have set up 25 low intertidal plots, each 0.25m^2 in size, where we randomly assigned the following five treatments (five replicates of each): Natural *Egregia* (no manipulation), -*Egregia* (*Egregia* removed), No-Natural *Egregia* (no manipulation), +*Egregia* (transplanted *Egregia*), or +mimic *Egregia* (plastic *Egregia* mimic). We have conducted community surveys of sessile and mobile organism cover/abundance for two seasons (Summer 2019 and Winter 2020). We have also measured sand depth and temperature at both sites within all plots. Our data show temperature differences between plots with *Egregia* and without *Egregia*, confirming that *Egregia* can ameliorate heat stress when present. We predicted *Egregia* plots would trap more sand during the winter at all sites but have seen no strong evidence of sediment trapping in any treatment. We expect differences in understory species composition between southern California and northern Washington but predict plots with *Egregia* in both regions will have higher richness and abundance than plots without *Egregia*.

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