127-1 AARON GOODMAN, AMG*; LAUREN ESPOSITO, LAE; California Academy of Sciences, California Academy of Sciences ; *agoodman@calacademy.org*

Spatial and Ecological Niche Partitioning in Congeneric Scorpions

Species in the scorpion genus Centruroides Marx, 1890 (Scorpiones: Buthidae) are good candidates to study ecological niche partitioning due to their habitat plasticity, widespread geographic distribution, and presence of cryptic species. Currently, three species belonging to three subgroups of Centruroides are distributed along the Isthmus of Tehuantepec in southern Mexico, presenting a rare opportunity to study niche partitioning within a single genus. We examined the environmental, substrate, and habitat preferences of *Centruroides flavopictus*, Pocock, 1890, *Centruroides gracilis*, Latreille 1904, and *Centruroides rileyi*, Sissom 1995 within La Estación Biología Los Tuxtlas west of the Isthmus of Tehuantepec. Our results demonstrate habitat partitioning occurs along humidity, temperature, and elevational gradients, with *C. gracilis* preferring habitats of low humidity and high temperature and is predominantly found on the substrate in human-mediated habitats, "*"C. flavopictus"*" exhibited a larger range of humidity and temperature preferences but was found within secondary and primary forest, and *C. rileyi* had the greatest specificity of low temperature and high humidity on trees within primary forest. Furthermore, *C. rileyi* was found significantly higher in trees than *C. flavopictus*. This study represents the first example of niche partitioning within a genus of arachnid, and the first description of the ecological niche in an arboreal-specialist scorpion.

56-5 ABBOTT, EA*; DIXON, GB; MATZ, MV; University of Texas; *evelyn.abbott@utexas.edu*

Disentangling coral stress and bleaching responses by comparing gene expression in symbiotic partners

Coral bleaching—the disruption of the symbiosis between a coral host and its endosymbiotic algae—is associated with environmental stressors. However, the molecular processes are not well understood, and no studies have disentangled the transcriptional bleaching response from the stress response. In order to characterize general stress response, specific stress responses, and the bleaching response, we isolated host and symbiont RNA from fragments of Acropora millepora which were exposed to 5 different stress treatments. We hypothesize that under stress conditions, the coral host, and not the symbionts, become stressed. If this hypothesis is correct we predict that the host may upregulate genes involved in oxidative stress, immune response, heat shock proteins, or lipid metabolism; we also expect that the symbiont would upregulate genes involved in growth and uptake of nutrients. Additionally, it is unknown whether the host or the symbiont initiates bleaching. Because symbionts are horizontally acquired, their success is not linked to the survival of the host. Thus, we hypothesize that when the host becomes stressed, the symbionts initiate bleaching. To capture the bleaching response, ambient conditions were reestablished after treatments and samples of RNA were taken at multiple time points, between 8-16 hours after the treatment. The RNA was sequenced with tag-based RNA sequencing and the data were analyzed using DESeq and WGCNA. If the symbionts initiate bleaching, we expect that the expression profile of the symbionts will resemble symbionts in the free-living state—such as upregulation of genes involved in sexual reproduction and motility. Conversely, if the host initiates bleaching we expect to upregulation of genes involved in immune response, exocytosis, or nutrient transport.

58-5 ABZHANOV, A; Imperial College London and Natural History Museum, United Kingdom; *a.abzhanov@imperial.ac.uk*

Phylogenetic Principles and Morphogenetic Mechanisms for Evolvability in Adaptive Radiations

Understanding the origins of morphological variation is one of the chief challenges to the modern biological sciences. Cranial diversity in vertebrates is a particularly inviting research topic 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 is revealing how particular changes in developmental genetics can produce morphological alterations for natural selection to act upon, for example in generating adaptive radiations.

29-7 ACHARYA, R*; CHALLITA, EJ; BHAMLA, MS; Georgia Institute of Technology; *racharya33@gatech.edu*

Ultrafast Finger Snap is Mediated by a Frictional Skin Latch

The snap of a finger is a ubiquitous motion that has been seen across cultures and times. Using high-speed imaging, we analyze finger snap dynamics for the first time. We find that the mechanics of the snap are strongly mediated by human skin friction, which acts as a latch to generate rapid motion. The skin frictional latch is optimally tuned to enable maximum kinematic performance as the angular accelerations observed during a snap are one of the fastest human motions known. A simple scaling relationship is found that links the latch geometry to the performance of snapping motion across multiple organisms from termites to humans. Ultimately, our work reveals how friction between surfaces can be harnessed as tunable and scalable latching mechanism, with applications ranging from increasing grip in biomedical prosthetic surfaces to generating high force and accelerations in tiny robots.

52-3 ACKERLY, KL*; ESBAUGH, AJ; The University of Texas at Austin; *klackerly@utexas.edu*

Impacts of temperature acclimation and oil exposure on aerobic performance in red drum, Sciaenops ocellatus

Aerobic scope, the difference between minimum metabolic requirements and maximum metabolic capacity, is an important metric affecting ecological success in fishes. Crude oil exposure can impair cardiorespiratory function in fishes, which reduces maximum metabolic rate and aerobic scope, and may impair ecological performance. However, oil exposure is not the only environmental stressor that can influence aerobic scope, especially in areas affected by crude oil spills. Temperature fluctuations, even within an organism's thermal window, are also known to significantly impact overall metabolic performance, yet there has been little effort to explore how oil exposure impacts metabolic performance across temperatures. Our goal was to investigate the effects of 24h acute oil exposure on the metabolic performance of red drum, *Sciaenops ocellatus*, following 3wk chronic exposure to four ecologically relevant temperatures. Our results show that individuals acclimated to higher temperatures had significantly higher metabolic demands compared to individuals at lower temperatures, which resulted in significantly decreased tolerance to low oxygen conditions. As predicted, crude oil exposure resulted in significantly lower maximum metabolic rates at all temperatures except the lowest. These results suggest that acclimation to lower temperatures may mediate the insult of injury to metabolic performance following exposure to crude oil.

55-3 ADDIS, AE*; JANZEN, FJ; BRONIKOWSKI, AM; Gonzaga University, Iowa State University; *addis@gonzaga.edu*

A Role of Insulin-Like Growth Factors in Mediating Trade-Offs Between Growth and Reproduction in Painted Turtles

A central tenet of life-history theory predicts the existence of energetic trade-offs. A classic example of these trade-offs is the energetic investment in reproduction versus self-care, including growth. Most studies investigating such trade-offs are of a demographic nature; many fewer investigate the physiological mechanisms that facilitate such trade-offs. Painted turtles (*Chrysemys picta*) are an excellent organism in which to investigate physiological mechanisms associated with the trade-off between reproductive effort and growth because they exhibit indeterminate growth, meaning, for one, that they continue to grow even after reaching reproductive maturity. In this study, we investigated the putative role of insulin-like growth factors (IGF-1 and IGF-2) as hormonal mediators of energetic investment. We collected blood samples from known-age females after oviposition; size and age are positively correlated in this population. We found that while age is positively correlated with clutch size, age does not affect IGF-1 or IGF-2 levels. However, we did find a three-way interaction among IGF-1, IGF-2, and age on clutch size. This complex interaction is not surprising considering the multitude of effects IGFs have. These results superficially suggest that that how IGFs influence reproductive output varies based upon age. These results will be explored in greater detail in this talk.

71-1 ADEOLA, FI*; LAILVAUX, SP; University of New Orleans, New Orleans, LA; *fiadeola@uno.edu*

The Influence of Dampened Locomotor Function on Calling Structure in the house cricket Acheta domesticus

Secondary sexual displays are important determinants of fitness in animals. Although variation in such displays are of keen interest to evolutionary biologists, the factors driving such variation are often poorly understood. Intrinsic factors such as individual condition, motivational state, or locomotor capacities in the case of dynamic displays could potentially affect aspects of male displays, which in turn can affect the probability of obtaining successful mating outcomes. We manipulated aggression and locomotor capacities in male house crickets, *A. domesticus* by synthetically blocking the octopamine receptors that influence aggression and skeletal muscle function. We then measured male courtship calls and analyzed the call structure to quantify the differences in the opportunity in selection based on the changes in dominant frequency, pulse duration intervals between chirp and trill in treated vs untreated males. By manipulating the ability of males to produce calls, which are driven by muscular contractions, we were able to reveal the influence of dampened locomotor function on male auditory displays

28-7 AHMED, S*; SHEARER, B; O'BRIEN, H; Northeastern State University, Tahlequah, NYU School of Medicine, NY, OSU Center for Health Sciences, Tulsa; *haley.obrien@okstate.edu*

The Hemodynamics Of The Carotid Rete In The Brown Greater Galago, Otolemur crassicaudatus

Galagos, lorises, and tarsiers, have the unique ability to rotate their heads ~180°. In most other primates, such extended head rotation results in transient loss of consciousness from decreased cerebral arterial perfusion. Mechanisms for maintaining consciousness during head-turning in primates are unknown. Here, we hypothesize that an internal carotid arterial meshwork known as the carotid rete facilitates this behavior. Retia are uncommon among primates and have dramatically different hemodynamic properties than singular vessels. Modified from Ohm's law, vascular resistance is modeled after series and parallel electrical circuits. Contiguous arteries are conceptualized as vessels in series, and retia are modeled in parallel, which decreases resistance by providing numerous avenues for blood flow. We develop 2 hemodynamics models: 1) vascular resistance of the carotid rete in its standard anatomical orientation, and 2) the vascular resistance when the branches that form the carotid rete are reduced by 50%, stimulating head turning. We based these models on digital 3D renderings of the arterial pattern constructed from microCT scans of cadaveric galago specimens injected with radiopaque latex . We find that, because of the carotid rete's many interconnecting branches, the reciprocal resistance of this parallel circuit reduces resistance and maintains flow, even when retial branch lumen is decreased by half. Thus, we provide evidence that the carotid rete may help to continually supply blood to the brain through a mechanism of decreased resistance by providing multiple routes for blood to flow during the commonly observed behavior of extreme cervical rotation in galagos.

56-1 AICHELMAN, HE*; BOVE, CB; CASTILLO, KD; BOULTON, JM; KNOWLTON, AC; NIEVES, OC; RIES, JB; DAVIES, SW; Boston University, UNC Chapel Hill, UNC Chapel Hill, Boston University, Northeastern University, Boston University, UNC Chapel Hill, Northeastern University; *hannahaichelman@gmail.com*

Time Course Physiology of Caribbean Corals Reveals Divergent Responses to Global Change Stressors

Global change is threatening coral reefs, with rising temperatures leading to repeat bleaching events (dysbiosis of coral hosts and symbiotic algae) and increasing pCO_2 causing reductions in calcification. Global bleaching events reveal fine-scale patterns of coral survival; however, the traits that lead to success under stress remain elusive. We conducted a 95-day laboratory experiment to investigate the physiological responses of two Caribbean reef-building coral species (*Siderastrea siderea* and *Pseudodiploria strigosa*) from two distinct reef zones on the Belize Mesoamerican Barrier Reef System under ocean warming (28, 31°C), acidification (~400–2800 µatm), and the combination of the two. Calcification, total host protein and carbohydrate, Chlorophyll *a* pigment, and symbiont cell density were quantified every 30 days to characterize the acclimatory responses of each coral genotype and their symbionts. Holobiont physiology of the two species was differentially affected by these stressors, and changed over time. While *S. siderea* was more negatively affected by increased pCO_2, *P. strigosa* was more negatively impacted by elevated temperature, particularly after chronic exposure. Reef zone differences in calcification and total protein were also apparent in *P. strigosa* in response to experimental treatment. By tracking holobiont physiology through time, this experiment highlights that focusing on average trends over the experimental interval can obscure the complexity of corals' responses through time, and provides a framework for future studies to consider when investigating such long-term acclimatory responses.

6-1 AIELLO, BR*; SPONBERG, S; Georgia Institute of Technology; *baiello3@gatech.edu*

The visual perception of moving flowers during the flower tracking behavior in descending neurons in the hawkmoth, Manduca sexta

The visual identification of externally moving targets allows animals to locate and track predators, mates, and food sources. Insects that routinely track small targets have dedicated neurons in their brain and ventral nerve cord (VNC) that selectively respond to targets of various size. The moth flower tracking behavior, where a feeding moth tightly tracks the 3D motion of a swaying flower, relies on acquiring and acting upon both self-motion (wide field visual movement of the background) and the external motion of a flower. Emerging evidence suggests that some descending neurons in the moth VNC selectively respond to wide field or small target cues while others respond generally. It is unknown which class(es) of moth VNC neurons are responsible for encoding flower motion. To answer this question, we recorded the response of descending VNC neurons to wide field motion (WFM), small target, and flower stimuli using multielectrode arrays in tethered hawkmoths, *Manduca sexta*. We find that VNC neurons respond to moving flowers, and some neurons can have directional selectivity. Over 80% of the recorded neurons have a large overlap in response to the three classes of stimuli presented; neurons that are sensitive to flowers can also respond to either WFM, target, or all three types of stimuli. Not all cells are universally responsive and some show selectivity to flower stimuli, being silenced by or unresponsive to either wide field or small target stimuli. These results show that descending neurons of the moth VNC can have overlapping and unique selectivity to both target and flower stimuli, suggesting that the visual system of insects can be evolutionary tuned to the life history and ecologically relevant stimuli of a given species.

108-2 AKANYETI, O*; FETHERSTONHAUGH, S; Aberystwyth University; *ota1@aber.ac.uk*

A kinematic chain model to quantify undulatory locomotion in animals and robots

Undulatory locomotion is ubiquitous among soft-bodied animals and it inspires novel robot designs. However, manufacturing flexible robots is not straightforward due to technological constraints. Compared to their biological counterparts with high degrees of freedom, robots need to navigate around with a limited number of actuators. To bridge the gap between biology and engineering, we present a novel approach to identify the minimum number of segments required to describe the body movements of undulatory animals accurately. We use a kinematic chain model which consists of a series of linear segments with connected joints. We use empirical data and least square methods to automatically estimate the model parameters (i.e. number and position of joints) so that the difference between predicted and measured motion is minimized. We tested our approach to describe the midline kinematics of 10 fish species with varying body length (L), morphology and flexibility during steady swimming (up to 5 L s^{-1}). Our preliminary results indicate that the minimum number of segments that can describe the midline kinematics with 95% accuracy vary significantly between species (e.g. five segments for Northern barracuda, *Sphyraena borealis*, and ten segments for Clown knifefish, *Chitala ornata*). The position of the most anterior joint (connecting segment one and two) also varies between species (e.g. 0.5 L for barracuda and 0.2 L for knifefish). The goal of this research is to develop an analytical tool that describes animal movements with parsimonious kinematic models. These models can be used by biologists to quantify movement capability of animals, by roboticists to enhance the design of underactuated robots, and by software engineers to generate realistic animal movements for computer simulations.

135-1 AKIN, DR*; GEHEBER, AD; Auburn University, University of Central Missouri; *dza0043@auburn.edu*

Morphological divergence of a stream fish in altered flow: teasing apart the influences of natural selection and plastic response on body shape

Cyprinella lutrensis is historically a stream dwelling minnow species (Family Cyprinidae) native to Missouri. Now, via damming, *C. lutrensis* occurs in both streams and reservoirs, including those of the Osage River drainage. The construction of Truman Dam (completed in 1979) has resulted in relatively high abundances of *C. lutrensis* within the reservoir and its surrounding tributaries. The widespread distribution of this species across the reservoir and connected streams provided an optimal study system for testing the effects of habitat alteration (through stream impoundment) on fish populations. Specifically, we were interested in the effects of flow alteration on *C. lutrensis* body shape. We hypothesized that populations in systems with no flow (i.e., reservoirs) would have reduced body shape streamlining. This was predicted due to the known importance of fish body form as it relates to locomotion in differing environment types. Here, we assumed that body streamlining would be beneficial for swimming in flowing environments. Analyses of morphology comparing *C. lutrensis* samples taken from Truman reservoir to samples taken from surrounding streams in the Osage River watershed showed significant differences in body shape between reservoir and stream populations, which indicated greater streamlining in stream populations. One possible mechanism of change (flow induced phenotypic plasticity) was tested in the lab using stream flow mesocosm units. This experiment also yielded significant results in support of the original hypothesis, and displays rapid phenotypic change dictated by environmental factors. Methods used, result implications, and future directions of study will be discussed.

136-7 ALBERTIN, CB*; PARNAIK, R; RAGSDALE, CW; Marine Biological Laboratory and University of Chicago, University of Chicago; *calbertin@mbl.edu*

Heterodox Ligands in an Ancient Signaling Center in Octopus Brain

Widely shared across metazoan neural development is a transcription factor network implicated in anterior-posterior brain patterning, including *OTX* anteriorly, the *HOX* genes posteriorly and an intercalated cassette of *GBX*, *PAX2/5/8* and *ENGRAILED*. In vertebrates, this cassette identifies the midbrain-hindbrain boundary, the site of a prominent signaling center known as the isthmic organizer (IO), which expresses the signaling ligands *FGF8* and *WNT1*. Outside of the vertebrates, soft-bodied cephalopods have the largest brains. We explored the role of these highly conserved developmental control genes with in situ hybridization experiments on *Octopus bimaculoides* embryos. We found that anterior *OTX*, posterior *HOX1* and an intercalated IO transcription factor cassette are readily demonstrated in octopus embryogenesis. Moreover, the IO cassette coincides with a morphological depression in the ectoderm (the "cleft"). The cleft in turn marks out the major structural transition in the prospective cephalopod brain, that between the subesophageal and supraesophageal masses. We found that the cleft, like the vertebrate midbrain-hindbrain boundary, is a major signaling center. It harbors most of the major developmental signaling molecules, including *HH*, *DPP* and multiple *WNT* genes. *FGF8* and *WNT1* are, however, absent. Our findings with this lophotrochozoan indicate that, even at the same stage of animal development, anterior-posterior signaling centers can show comprehensive transcription factor conservation in the face of marked signaling ligand lability.

96-4 ALEXANDER, SLM; BHAMLA, MS*; Georgia Institute of Technology; *saadb@chbe.gatech.edu*

Ultrafast and underdamped: Slingshot spiders design conical webs for ambush predation and self-survival

Numerous living systems employ biological springs and latches to mechanically amplify their power for ultrafast movements. The biomechanics of power-packed, ultrafast motion in both natural and robotic systems is an emergent topic of study, but is often one-sided, focusing solely on storage and amplification of power. How ultrafast organisms dissipate excess energy and prevent catastrophic self-destruction remains relatively unexplored. In this work, we focus on the dynamics of `Slingshot Spiders' to study both the energy storage and energy dissipation mechanisms involved in repeatable ultrafast motion. We bring high-speed cameras to the Amazon Rainforest and quantify the ultrafast hunting dynamics of the ``Slingshot Spider" (SS) for the first time, since its first naturalist description almost a century ago. We discover that the SS exploits the stored elastic energy of their conical silk webs `springs' to achieve accelerations exceeding 1300 m/s2 (130 g-force) which, is the fastest full body motion achieved by an arachnid. The web release mechanism occurs in less than a millisecond, achieving accelerations faster than a flea jump. This need for speed underscores an ambush hunting strategy, where SS explosively hurls itself and its web to catch giant flying insects in mid-air, increasing its predation success compared to traditional insect-web-collision strategy. Finally, we explore the design space of SS's dynamics utilizing a damped oscillator model, uncovering the dual-functionality of the web structure: to both load elastic energy for powerful motion and to efficiently dissipate excess energy for self-survival. Our work highlights an underappreciated, yet crucial evolutionary trade-off in ultrafast systems that enables them to safely execute their extreme movements hundreds of times over their lifetime, without compromising on power output.

79-2 ALONGE, MM*; DANIELS, DT; SCHOBEL, T; BENTLEY, GE; University of California, Berkeley; *mattina.alonge@berkeley.edu*

Flexible Expression of Sickness Behavior and Parental Care Across Stages of Avian Reproduction

Organisms are often challenged with balancing energy demand between competing physiological processes. For example, the demands of mounting immune responses can negatively impact reproductive success. Despite known costs of female reproduction, the mechanisms underlying parental behavior/physiology in immune-challenged female birds are unknown. Conceptually, reproductive life history trade-offs are not new, but no study has compared potential shifts in prioritization across stages of reproduction in female birds according to prior energetic investment. Breeding female zebra finches were injected with LPS or 0.9% saline on day 7 of incubation. Another cohort was injected similarly 7 days after hatching; a period of active provisioning. Nest attendance, flights, hops, and time at rest were recorded, and parental (and nestling) weights taken 0, 6, and 24 hrs post-injection. Blood was sampled at 0 and 6 hrs for CORT and PRL measurements. Our current data show that although LPS-treated incubating females significantly decreased activity (flights, hops), increased time spent at rest, and lost substantial mass this did not interfere with their parental behavior. Males increase time in the nest when their female mate is healthy. Analysis for nestling provisioning stage is underway. If trade-offs occur due to energy limitation, we predict females will maintain parental care during incubation but prioritize self-maintenance during increased energetic demands of nestling provisioning. Alternatively, predictions may be shaped by an investment perspective rather than purely energetic one, where individuals are likely to abandon a current reproduction when challenged in an earlier stage and likely to sacrifice self-maintenance at a later stage, given the amount of effort invested fitness.

89-5 ALTMAN, KA*; HALL, EM; ROLLINS-SMITH, LA; OHMER, MEB; RICHARDS-ZAWACKI, CL; University of Pittsburgh, PA, Vanderbilt University, Nashville, TN; *karie.altman@pitt.edu*

Effects of pond drying on northern leopard frog development, growth, immune function, and susceptibility to Batrachochytrium dendrobatidis

As the climate changes, warmer temperatures are expected to increase the rate at which ephemeral ponds dry, which will likely have consequences for amphibians. Reduced hydroperiods can influence larval growth and developmental rates and might also impact amphibian characteristics post-metamorphosis, such as immune function and disease susceptibility. We predicted that as ponds dry faster, (1) tadpoles would metamorphose quicker but at a smaller size, and (2) metamorphosed frogs would have reduced immune function and be more susceptible to disease. We tested these predictions by raising northern leopard frogs (*Lithobates pipiens*) in mesocosms assigned to one of four drying treatments: no-, slow-, medium-, and fast-drying. After frogs metamorphosed, we repeatedly exposed a subset of animals to *Batrachochytrium dendrobatidis* (Bd) and measured immune function in another subset of animals. Contrary to our first prediction, drying rate alone had no effect on development time or size at metamorphosis. In metamorphosed frogs, drying rate did not affect Bd load in our exposure experiment or T-cell response. However, T-cell response increased with larval period regardless of drying treatment, indicating that a longer larval period can be beneficial post-metamorphosis. Furthermore, frogs in the slow-drying treatment had a greater B-cell response than those in the medium-drying treatment, showing that some effects of reduced hydroperiod experienced in the larval period can persist post-metamorphosis. Taken together, our results show that the effects of pond drying rates on amphibians are not straightforward and require further study.

47-1 ALVARADO, SG*; KRUPAKAR, H; Queens College CUNY, GE Healthcare; *sebastian.alvarado@qc.cuny.edu*
Developing an automated pipeline for quantifying animal pigmentation using deep learning
Coloration is a salient trait across the animal kingdom that can allow an individual to become cryptic, conspicuous, or social. While some developmental patterns in pigmentation are static, others are dynamic to changes in their ambient environment. Despite a great deal of study in developmental pigmentation patterns, little is known about how environmental cues shape the developmental plasticity that allows an individual to change color. One approach to understanding these processes is through the lens of epigenetic modification and DNA methylation. DNA methylation of cytosine residues in gene promoters is a reversible modification that silences gene function in vertebrates. Since DNA methylation is involved in programming various cellular functions, it is likely that it facilitates molecular changes as pigment-bearing cells (chromatophores) change their composition during animal color changes and behavioral transitions. We used an African cichlid model system (Astatotilapia burtoni) with discrete reversible color morphs (blue and yellow) to dissect the underlying molecular processes that lend plasticity to animal coloration. Our findings suggest that epigenetic processes such as DNA methylation lend plasticity to coloration, which is an important hallmark driving selection. Furthermore, since genetic diversity does not account for the phenotypic diversity seen in Lake Tanganyika, we propose that DNA methylation may contribute to the processes that have led to the adaptive radiation of cichlids in East African Great Lakes.

24-3 AMONETT, SD*; BALENGER, SL; University of Mississippi; *sdamonet@go.olemiss.edu*
Mother Knows Best: Immune-based Maternal Effects in Response to Mycoplasma gallisepticum Infection in Eastern Bluebirds (Sialia sialis)
Neonates lack adaptive immunity and are vulnerable to pathogens. In fact, adults carrying pathogens may transmit infections to their neonate offspring. In response to pathogens, mothers transfer passive immunity to offspring by transmitting antibodies via milk or yolk. Mothers previously or currently infected with a pathogen can transfer pathogen-specific antibodies to newborns, granting them immunological protection until they can synthesize their own. In birds, antibodies are deposited before eggshell formation within the mother's oviduct. It was recently discovered that wild eastern bluebirds (*Sialia sialis*) are common hosts of the avian pathogen *Mycoplasma gallisepticum* (MG). Adult bluebirds exposed to MG in the wild mount an adaptive immune response in the form of circulating antibodies. Serum samples collected in the breeding season of 2018 and 2019 showed that adult female bluebirds transmit MG-antibodies to their offspring, and these antibodies persist in young approximately 5 days post-hatch. PCR analysis of choanal cleft (throat) swabs from entire bluebird families indicate that both male and female adults may transmit MG infection horizontally, most likely through feeding behaviors. We will discuss the impact of vertical transmission of this pathogen and protective antibodies on the fitness of wild eastern bluebird nestlings.

40-6 AMPLO, HE*; FLAMMANG, BE; Rutgers Univeristy-Newark, New Jersey Institute of Technology; *hea7@njit.edu*
Frogfish Pectoral Fin Functional Morphology
Frogfish (Family Antennariidae) are highly derived benthic, teleost fishes capable of performing three modes of locomotion: jetting, swimming, and substrate-based locomotion. Previous literature has described how frogfish use their limb-like pectoral fins in order to "walk" underwater and describe the crutching versus alternating fin-fall gaits. Frogfish plant their distal pectoral fin into the substrate in order to walk, but have their fins outstretched while jetting and tucked against the body wall while swimming. Frogfish have a unique ball-in-socket shoulder joint morphology and fourteen different pectoral fin muscles, which may allow them to seamlessly transition between these three modes. While the presence of this extreme limb rotation has been described, the mechanism behind it is less clear. In this study, the pectoral fin and pectoral girdle of the Sargassum frogfish, *Histrio histrio*, and the shaggy frogfish, *Antennarius hispidus*, are described using microCT scanning, PTA staining, and gross dissection. The functional implications of forelimb rotation in walking will be compared to locomotor kinematics of other fishes and tetrapods.

138-6 ANDERSON, RC*; ZIADI, P; NIEDERHAUSER, J; Florida Atlantic University, Davie FL; *andersonr@fau.edu*
Why so many song types? Song sharing, song type matching, and the agonistic function of song type repertoires in Bachman's sparrow
Male Bachman's sparrows (*Peucaea aestivalis*) have repertoires of 33-55 primary song types as well as repertoires of "warble songs" and call types. How are these large vocal repertoires used during territorial disputes? We quantified responses to simulated territorial intrusions (STI) and found that more aggressive males sang fewer high-amplitude primary songs and more low-amplitude ‘‘whisper songs.'' On average males share 47% of their song types (range 28-81%) Song sharing is not higher among adjacent neighbors and does not decline significantly across a distance of 3.3 km. High song sharing suggests a role for song type matching during agonistic signaling. In a second STI experiment 16 of 22 (72%) males matched during playback of their own songs and 14 of 22 (64%) matched more than once but these rates do not exceed the chance matching rate. Markov-chain analysis of singing behavior (n=8) suggests that males deliver their songs in sequences with some song types grouped together in a predictable order. Playback of a bird's own song sequence did not increase the likelihood of song matching for most birds, but 4 of 21 birds matched at high rates when played their own sequence. Birds that matched playback were not more aggressive than those that did not match suggesting that song matching is not an immediate threat signal in this species.

S10-2 ANDERSON, PSL; University of Illinois, Urbana-Champaign; *andersps@illinois.edu*

Keep It Simple Stupid: Using simple models to explore how physical laws influence the evolution of biomechanical systems across clades

The field of comparative biomechanics strives to understand the diversity of the biological world through the lens of physics. To accomplish this, researchers apply a variety of modelling approaches to explore the evolution of form and function across phylogeny. These models range from basic lever mechanics, to physical models, to intricate computer simulations. While advances in technology have allowed for increasing model complexity there is still great insight to be gained through the use of relatively simple models with few parameters. Models are not literal representations of reality but simplifications of the events, scenarios or behaviors being studied. Any model, regardless of how complex, must make assumptions; simple models just make more assumptions than complex ones. While a complex model may account for more parameters simultaneously, simple models allow for individual parameters to be isolated and tested systematically, as seen in studies on vertebrate tooth form. More generalized models with fewer parameters means that a model can be applied across a wider range of organisms. As an example, physics models have been used to identify trade-offs common to power-amplified systems across a wide range of organisms. Simple models also make good starting points for comparative studies, allowing for complexity to be added as needed. To demonstrate these ideas, I perform a case study on body form in ants. Basic center of mass calculations are used to explore constraints and adaptation to proportions in ant body form across major ant clades. Results illustrate how simple, low-parameter models both highlight fundamental biomechanical trends, and aid in crystallizing specific questions and hypotheses for more complex models to address.

72-7 ANDERSON, CV*; REITER, PA; ROBERTS, TJ; Univ. South Dakota, Vermillion, Brown University, Providence; *Christopher.V.Anders@usd.edu*

Examining the early stages of adaptive radiation in Anolis roquet from Martinique

Caribbean *Anolis* lizards have become a model system for the study of adaptive radiation and coevolution, whereby anoles have diversified to specialize in the use of different parts of their structural habitat. The resultant ecomorphs exhibit consistent morphology-to-habitat use relationships on each island, such that the same ecomorph on different islands look remarkably similar. They also exhibit similar morphology-to-performance relationships whereby their performance capabilities are closely related to their morphology and vary among ecotypes. Unlike other Caribbean islands, the island of Martinique is host to a single species, *Anolis roquet*. Across the island, however, *A. roquet* inhabits disparate environments. The lizards that occupy these differing habitats show noticeable variation in their physical characteristics, having previously been described as six different subspecies and as different ecotypes. We examined the morphology, sprint and bite performance, and muscle contractile physiology of two forms of *A. roquet* from a montane forest habitat and a xeric coastal habitat. We found significant differences in morphological dimensions, along with differences in some whole organism performance measurements between these two forms. Muscle contractile physiology, on the other hand, generally did not vary between these forms. Differences appear particularly prominent in head dimensions and bite force, possibly due to these forms specializating to different prey items or varying in their conspecific interactions. These results suggest that morphology and performance may specialize to novel environments and functional demands before muscle contractile physiology. Such patterns thus provide insight into the process of adaptive radiation and the effects of habitat variation on *Anolis* lizards in the absence of species level divergence.

74-5 ANDERSON, RA; Western Washington University; *Roger.Anderson@wwu.edu*

Using among-year climate conditions and climate indices to predict consequences for multiple trophic levels: plants, insects and lizards

In the northern extreme of the Great Basin desert scrub, climate variation is exemplified not only by the contrasts of La Nina and El Nino years, but also by comparing temperature and rainfall differences among consecutive years, across a fifteen-year span. As an ecosystem strongly limited by water resources, the among-year contrasts in temperature and rainfall in the desert scrub, along with aridity indices and evapotranspiration indices, can be used to predict contrasting outcomes among years in productivity at multiple trophic levels: 1) NDVI as a proxy of primary productivity, 2) abundances of arthropods (the primary and secondary consumers), 3) specific prey of lizards, 4) feeding rates by lizards (the secondary and tertiary consumers), 5) lizard body condition and 6) reproductive output of lizards, with special focus on the Long-nosed Leopard Lizard, *Gambelia wislizenii*, which eats vertebrates and arthropods. Trophic consequences of climate variation among years do correlate with indices, with the caveat that indices only approximate the dynamic timing and levels of precipitation and temperature.

83-2 ANDREASEN, VA*; YAP, KN; YAMADA, K; WILLIAMS, A; ZIKELI, S; KAVAZIS, AN; HOOD, WR; Auburn University, AL; *vaa0008@auburn.edu*

The impact of maternal corticosterone on offspring morphology and mitochondrial physiology

The effects of maternal stress on offspring phenotype remain equivocal. An increase of circulating glucocorticoids in reproductive females may augment allocation of resources towards self-maintenance and away from offspring. Thus, elevated circulating glucocorticoids may negatively affect offspring development. However, maternal stress may induce preparative responses in offspring, such as higher tolerance to oxidative stress and more efficient mitochondria, which could positively impact survival. If early life experience is a good predictor of future environments, then increased mitochondrial performance may provide a benefit towards survival in poor conditions. To test this hypothesis, corticosterone (CORT) was administered orally to female mice from days 7 to 21 after parturition. Thus, offspring were indirectly exposed to CORT through the mother's milk and aspects of their mitochondrial physiology were investigated at two timepoints, 38 and 70 days of age. At both ages, we isolated mitochondria from liver and skeletal muscle to measure respiratory control ratio (RCR) and reactive oxygen species (ROS) production. Preliminary results show that skeletal muscle RCR was higher while ROS was lower in adult offspring (70 days old) exposed to maternal CORT. These effects suggest potential benefits to post-natal stress exposure which could assist in predator escape. Experimental pups had a lower body mass than control pups at both ages, though these differences were marginally insignificant. Data on oxidative damage, mitochondrial density and fecal CORT levels will also be presented.

39-3 ANSELMO, CM*; BUTLER, JM; MARUSKA, KP; Louisiana State University, Baton Rouge; *cansel5@lsu.edu*
Can you feel me now?: The lateral line system mediates reproduction in an African cichlid
The mechanosensory lateral line system (LLS) of fishes is fundamental for detecting water movements and functions in schooling, orienting in currents, locating prey, and detecting and evading predators. However, less is known about its role in social interactions. Previous work in our lab showed that *Astatotilapia burtoni* males use mechanosensory information to mediate male-male territorial interactions. Many fishes also produce water movements during reproductive interactions, but little is known about the role of the lateral line system in reproduction in any of the ~30,000 fish species. To understand the importance of mechanoreception in reproductive contexts, we compared behavioral interactions and neural activation patterns between LLS-intact and LLS-ablated females exposed to intact males. Our data shows that males are less-likely to court LLS-ablated females, who are then less-likely to positively respond to those courtship attempts. Spawning also occurred less often in trials with LLS-ablated females, illustrating that lateral line information is important for reproductive success. To investigate neural processing of reproductively-relevant mechanosensory information, brains were collected after behavior trials and stained for the immediate-early gene *cfos* as an indicator for neural activation. LLS-ablated and LLS-intact females had different activation patterns in some sensory and socially-relevant brain regions. These results reveal that mechanosensory information is also processed in known socially-relevant regions. This study is the first to integrate behavioral and neural activation analyses to show the importance of the lateral line system in mediating reproductive communication in any fish species.

75-5 ARIAS, AA*; BALL, AM; AZIZI, E; University of California, Irvine; *adriena@uci.edu*
Passive mechanical properties of crocodilian limb muscles correlate with in vivo function
The passive mechanical properties (i.e. passive stiffness) of muscle have been shown to influence the region of the force-length (F-L) curve over which it operates. Previous work in anurans has shown that muscles with distinct *in vivo* functions (i.e. energy production *vs.* dissipation) vary in passive mechanical properties, but it remains unclear whether this pattern is broadly held across terrestrial vertebrates or restricted to highly-specialized muscles. Here we use results of inverse dynamics analyses in juvenile alligators to deduce the *in vivo* functions of limb muscles during walking, and subsequently characterized the F-L properties of two different limb muscles *in situ*. Results from inverse dynamics suggest that elbow extensor muscles undergo a period of negative work (eccentric contraction) and ankle extensors muscles primarily produce positive (concentric contraction) or zero (isometric contraction) work during stance phase of walking. Based on these results and previously published anatomical data (Allen et al. 2010, 2014), triceps longus lateralis (TLL) and lateral gastrocnemius (LG) were chosen for muscle preparations. Our preliminary *in situ* results show that TLL passive force reaches 20% maximum isometric force (L_{20}) at shorter relative lengths when compared to LG. We also find that the slope of log-transformed TLL data is greater than that of LG (ANCOVA $p<0.05$), indicating an increase in stiffness of muscle that dissipates mechanical energy. These results suggest a causal link between a muscle's expected *in vivo* function and its passive stiffness, and this work in crocodilians expands the range of muscle passive stiffness literature to include reptiles and animals with semi-erect postures. Future work will determine the *in vivo* operating lengths of TLL and LG followed by *in situ* F-L characterizations to map where on their respective force-length curves these muscles operate at during walking.

116-2 ASSIS, BA*; AVERY, JD; TYLAN, C; EARLEY, RL; LANGKILDE, T; Penn State, University of Alabama; *bmd5458@psu.edu*
Honest Signaling, Sexual Conflict and Female Ornamentation: an Undesired Quality Signal?
Conspicuous sexual ornaments are uncommon in females of species with traditional sex roles, with such occurrences often attributed to genetic linkage of a trait selected for in males. In eastern fence lizards, males display colorful ornaments that are sexually selected, but any condition-dependent traits associated with ornament quality are unknown. Females may exhibit rudimentary ornamentation that carries reproductive costs, but it is unclear whether they display honest condition signaling as well. To investigate a potential adaptive role for female ornamentation in fence lizards, we used individuals from three populations to determine the relationship between ornament quality and typical condition-dependent traits in both sexes, while accounting for the effect of hormones normally associated with ornament development. In accordance with previous studies, we detected a strong relationship between testosterone levels during a specific developmental window and ornament quality at maturity. Ornament size and saturation were significantly correlated with body condition and immune response in males and therefore might signal individual quality, but these relationships were weaker or absent in females. It appears that ornament development in females is still sensitive, albeit more weakly, to androgen levels and condition-dependent traits. It is not known whether females employ this costly trait in intraspecific signaling, and thus its presence might indicate a scenario of intralocus sexual conflict. We speculate that females have largely reduced the energetic costs of ornaments by eliminating melanin deposition in these traits, while costs for iridophore production are not sufficiently high to drive females towards full sexual dimorphism.

S8-1 ASTLEY, H. C.; C, ; University of Akron; *hastley@uakron.edu*
Symposium Introduction - Long Limbless Locomotors Over Land: The mechanics and biology of elongate, limbless vertebrate locomotion
Elongate, limbless body plans are widespread in nature and frequently converged upon (with over two dozen independent convergences in Squamates alone, and many outside of Squamata). Despite their lack of legs, these animals move effectively through a wide range of microhabitats, and have a particular advantage in cluttered or confined environments. This has elicited interest from many disciplines interested in many aspects of their movements, from how and when limbless morphologies evolve to the biomechanics and control of limbless locomotion within and across taxa to its replication in elongate robots. Increasingly powerful tools and technology enable more detailed examinations of limbless biomechanics, and a combination of fossil discoveries and improved phylogenies have shed increasing light on the origins and evolution of limblessness, as well as the high frequency of convergence. Advances in actuators and control are increasing the capability of "snakebots" to solve real-world problems (e.g. search & rescue), while biological data has proven to be a potent inspiration for improvements in snakebot control. This symposium brings together prominent researchers on the topic from around the world, including biomechanists, physicists, and roboticists to foster collaboration and the exchange of ideas across disciplines and across taxa. The goal of this symposium is to identify major gaps in current knowledge and methods, promote links between biological and robotics researchers, and coordinate efforts to move the field as a whole forward. Support generously provided by the Company of Biologists and the Society for Experimental Biology.

S8-2 ASTLEY, H.C.; University of Akron; *hastley@uakron.edu*
Mechanics of Multi-articular Muscles Minimize Moments
The geometry of the musculoskeletal system, such as moment arms and linkages, determines the link between muscular functions and external mechanical results but as the geometry becomes more complex, this link becomes less clear. The musculoskeletal system of snakes is extremely complex, with several muscles which span numerous vertebrae, ranging from 10 to 45 vertebrae in the snake semispinalis-spinal (SSP) muscles (a dorsiflexor). Furthermore, this span correlates with habitat, with burrowing and aquatic species showing short spans while arboreal species show longer spans. Similar multi-articular spans are present in the prehensile tails of primates, the necks of birds, and our own digits. However, no previous analysis has adequately explained the mechanics of these multi-articular spans, either relative to mono-articular configurations or compared to greater or lesser spans. This talk uses well-established analysis techniques including the Method of Sections and the Minimum total potential energy principle to analyze the consequences of multiarticular muscle configurations. I show that multi-articular systems require a fundamentally metameric structure in which N joints require N muscles, as unconstrained internal degrees of freedom allow the system access lower potential energy states by sagging or buckling. For a cantilevered snake, increasing multi-articular span reduces both the force needed from any given muscle and the total muscular force needed across the entire muscular system. However, this improvement follows a hyperbolic distribution, with the greatest gains in transitions from mono-articular to spans of 2 or 3; all known snake SSP lengths fall into a region of much lower force with nearly linear slope and diminishing returns for extreme lengths. Continued work will examine dynamic locomotion and potential tradeoffs.

S11-5 AUDET, JN; Rockefeller University Field Research Center, Millbrook, NY; *jaudet@rockefeller.edu*
Comparative approaches for ecological and neurobiological correlates of innovation
In the wild, particularly in rapidly changing conditions, being capable of solving new problems can increase chances of survival. In the context of climate change, innovativeness is therefore undeniably a crucial trait. In the past few decades, birds appeared to be a taxa of choice to study innovation, thanks to the abundant literature of avian innovation reports. Innovation rate databases in birds have been successfully employed to assess relations between innovativeness and other traits such as invasion success, fitness and brain size. In order to assess more direct causes of variation in innovation, another approach consists in experimentally measuring innovativeness in captive wild animals using problem-solving tasks that mimic wild innovations. This method can allow for finer scale evaluation of ecological and neural correlates of innovation. In my talk, I will present results that were obtained using the latter approach, both at the inter-individual and inter-specific levels. I will show that such data can be used to 1) assess relations between problem-solving and a variety of cognitive and personality traits, 2) compare experimental behavioral data with other known traits of interest such as innovation rate or fitness, and, even more interestingly, 3) investigate neurobiological properties underlying variation in problem-solving and other cognitive traits. During my talk, I will present past data as well as ongoing projects utilizing the comparative approach at a neurobiological level, using state-of-the art molecular methods to answer our research questions.

20-4 AWDE, DN*; LECHETA, MC; UNFRIED, LN; JACOBS, NA; POWERS, B; BORA, K; WATERS, JS; AXEN, HJ; FRIETZE, SE; LOCKWOOD, BL; CAHAN, SH; TEETS, NM; University of Kentucky, Lexington, University of Vermont, Burlington, Providence College, RI, Salve Regina University, Newport, RI; *davidawde@gmail.com*
Genetic mechanisms of basal thermal tolerance in Drosophila melanogaster
Shifts in daily and seasonal temperatures have a considerable effect on the performance, survival, fitness, and geographic distribution of all taxa. Thus, upper and lower thermal limits are important predictors of an organism's ability to cope with thermal variability and the effects of climate change. The ability to respond to thermal stress involves heritable genetic components and short-term shifts in gene expression; however the extent to which these two mechanisms overlap is unknown. For this study we used the *Drosophila* Genetic Reference Panel (DGRP) combined with RNA-seq in a single lab strain (Canton-S) to identify the overlap in genetic and transcriptional mechanisms underpinning critical thermal minima (CTmin) and maxima (CTmax). In the DGRP, there was greater phenotypic variation in CTmin, which ranged from 1.75 to 8.55°C, compared to CTmax, which ranged from 38.75 to 40.65°C. Upcoming analyses will determine the extent of overlap between genes identified via Genome Wide Association mapping (GWAS) using the DGRP and those identified via RNA-seq analyses with Canton-S flies exposed to their thermal limits. Together these results will characterize the relative contribution of genomic variation and short-term shifts in gene expression that underpin the thermal stress response in *Drosophila melanogaster*.

15-5 BABIN, CH*; BELL, CD; University of New Orleans; *chbabin@uno.edu*
A global molecular phylogeny of chromosomal evolution in wild onions (Allium, Amaryllidaceae)
Polyploidy, the event of increasing nuclear chromosomes, is believed to be a significant driver of diversification among land plants. Mechanisms of chromosome number evolution include whole-genome duplication, half-genome increases (demi-polyploidy), gains or losses of single chromosomes that alter the DNA content of an organism (aneuploidy), or chromosome fission or fusion (ascending dysploidy or descending dysploidy, respectively). Considering the high variability in chromosome number transitions across multiple clades within angiosperms and the ancient genome duplication events responsible for their diversity, studies of non-model systems are necessary to close the gaps in our understanding of chromosomal evolution with respect to polyploid plants. *Allium* (Amaryllidaceae) is an ideal candidate for polyploid research because it is the largest genus in its family and includes numerous natural populations of diploid and polyploid species. Plants in this genus mainly occupy temperate climates in the Northern Hemisphere and include economically important ornamentals and cultivated crops such as leeks, garlic, chives, and onion varieties. Here, we present a global molecular phylogeny of *Allium* comprising 429 of approximately 800 species. We examined chromosomal evolution with chromEvol v. 2.0 (Glick and Mayrose, 2014) which uses likelihood-based methods for inferring the pattern of chromosome number change across a phylogeny. The ancestral base number was inferred to be n = 8, consistent with the most common haploid number of Old-World species. The best-fit model of chromosomal evolution indicated that chromosome transitions occurred through the constant gains and losses of single chromosomes as well as demi-polyploidization events, with the rate of chromosome gain events being approximately four to five times more likely to occur than half duplication and loss events.

140-2 BABONIS, LS*; RYAN, JF; MARTINDALE, MQ; Whitney Lab for Marine Bioscience, Univ of Florida, St. Augustine, FL , Whitney Lab for Marine Bioscience, Univ of Florida, St. Augustine, FL; *babonis@whitney.ufl.edu*

Things cells do

The concept of homology fuels many discussions (and frustrations) about the evolution of animal morphology. Little clarity comes out of these discussions due to a general lack of consensus about the general meaning of homology; however, we argue that a bigger problem lies in a lack of understanding about how the limited morphospace under which cells evolve can lead to erroneous conclusions that morphological similarity reflects meaningful homology. For example, the morphological similarity of the unicellular choanoflagellates to the choanocytes of sponges was the chief evidence used to place Choanoflagellata as the sister lineage to Animalia prior to the dawn of molecular phylogenetics. This placement was later reinforced by molecular phylogenies, artificially inflating the apparent value of morphological similarities. Given constraints on the biophysical capacity of membranes, cytoskeletal elements, and the surface area-to-volume ratio of the cell, we argue that eukaryotic cells really only do four things: grow/shrink, undergo membrane elaboration, adopt independent shapes, and gain/lose organelles. As such, cells with similar morphological features are expected to have arisen multiple times during the expansive diversification of animals. As a case study, we survey the evolutionary distribution of cells with apical cilia and microvilli across animals and summarize evidence for shared ancestry in a subset of these. We emphasize that cellular morphology alone is insufficient support for arguments of shared ancestry and propose a new standard for discussion of homology that requires evidence of embryological, genomic, and functional similarity as well.

9-1 BADGER, MA*; PERKES, AD; PFROMMER, BG; WANG, Y; MODH, A; DANIILIDIS, K; SCHMIDT, MF; University of Pennsylvania, Philadelphia, Pennsylvania; *mbadger@seas.upenn.edu*

From moments to months: Multi-timescale tracking and analysis of songbird social interactions in a smart aviary

Social networks are formed through the actions of individuals and the structure that emerges is central to processes occurring at several biological levels of organization. How individual actions modify social networks, however, remains an important and open question. In our study system, brown-headed cowbirds (*Molothrus ater*), females are known to influence male courtship behavior. The specific mechanisms behind this phenomenon have been difficult to discover, however, because interactions (e.g. body motions and vocalizations) between multiple pairs of individuals occur simultaneously and are difficult to classify without quantitative measurements. We used an array of eight cameras and 24 microphones followed by a computer vision pipeline to continuously record the position, posture, and vocalizations of cowbirds over the entire breeding season. With these data, we investigate how moment-to-moment interactions drive changes in the social network over months. Our data also provide a difficult setting containing multiple camera views, background motion, shadows, and changes in lighting, in which to test animal tracking, pose estimation, and re-identification algorithms.

112-3 BAIN, SR*; LOWER, SE; Bucknell University; *srb039@bucknell.edu*

Using Environmental Factors to Predict the Emergence Patterns of Firefly Species in Pennsylvania

How do environmental parameters affect the geographic distribution of organisms? Many organisms need to have specific conditions (temperature, sunlight, precipitation, etc.) in order to survive, develop, and eventually reproduce. The overall goal of this research project attempts to investigate environmental factors (air and soil temperature) influencing the species distributions of fireflies. Fireflies are a very widely admired organism but are vastly understudied; more information about their evolution, communication (in lighted and unlighted species), and physiology is being discovered about this organism everyday which makes it an interesting and current area of research. With that being said, there are many aspects of these organisms that still need to be researched which is where this study comes in. Flash patterns and DNA barcoding were used to identify which firefly species were present at three local field sites from May to August of 2019; abundances were also observed. That data, in addition to minimum and maximum air temperatures, were used to create a degree-day (mGDD) model. The degree-day model was adapted so it can be used as a predictive model of the various local firefly species found in years to come. Soil temperature was not put in this model because minimum and maximum values were not obtained daily. Many of the mGDD values for the different species found in this study matched up to previous findings; the ones that did not could have been because of geographic differences or speciation. Fireflies can be bio-indicators of environmental health; knowing more about how temperature affects when and where they emerge will begin to illustrate what could happen to firefly populations in relation to the continuation of climate change.

10-1 BAKER, CM*; BOYER, SL; GIRIBET, G; Harvard University, Cambridge, MA, Macalester College, St Paul, MN; *baker02@g.harvard.edu*

Phylogenomics and Biogeography of the Gondwanan Vicariant Harvestman Family Pettalidae (Arachnida, Opiliones)

We tested the hypothesis that Gondwanan vicariance contributed to the circum-Antarctic distribution of Pettalidae, a family of small, dispersal-limited arachnids whose phylogeny, based on morphological or Sanger sequence data, has until now been unresolved. We generated transcriptomic data for a phylogeny of sixteen pettalids, from nine genera. Data were analyzed using ML, Bayesian, and coalescence methods. The phylogenetic position of a biogeographically critical genus from Sri Lanka was further explored using quartet likelihood mapping and gene-wise changes in log likelihood scores. We also performed a dating analysis using fossil calibrations on a previously published Sanger-based phylogeny with near complete species sampling, and the backbone constrained to match our transcriptomic results. We then reconstructed the biogeographic history of the family under the DEC model, using the posterior distribution of our dating analysis to incorporate divergence time uncertainty, and looked for signatures of mass extinction in the family. We recover a mostly stable topology, with a clear division between a clade from landmasses of East Gondwana, and a grade from West Gondwana. Further interrogation of phylogenetic signal suggests a sister-group relationship between taxa from Sri Lanka and eastern Australia. Given the coincident timing and order of cladogenetic events with tectonic activity, Gondwanan vicariance can explain several diversification events in Pettalidae. Some divergences predate rifting, suggesting some level of ancient regionalization, though not trans-oceanic dispersal. Despite the fact that there likely has been widespread extinction in the family, especially across Antarctica and Australia, diversification analyses find a consistent rate of speciation throughout time.

103-4 BAKKEN, G.S*; SCHRAFT, H.A; ORDUNO-BAEZ, A; CLARK, R.W; San Diego State Univ.; *george.bakken@indstate.edu*
Temperature Dependences and Angular Resolution of the Pacific Rattlesnake Facial Pit.
The pitviper facial pit functions as a chamber-type "eye". Uniquely, rather than quantum detection, sensory endings detect temperature contrasts on the pit membrane produced by thermal radiation. A novel neural pathway transmits this thermal image to the optic tectum, where it is merged with the visual image. Computer models of image formation suggest an indistinct thermal image. Neural processing in the hindbrain sharpens the image, but further sharpening may occur and so the quality of the thermal image informing behavior is unknown. However, it is critical to ecological questions such as detecting prey and thermoregulatory targets against a cluttered thermal background. We are approaching this question by testing the response of Pacific rattlesnakes (*Crotalus oreganus*) to a target moving against a patterned background. Temperatures are chosen so that it can be detected only if the background is resolved. Selection of experimental conditions required knowledge of how, singly or in combination, body, neurosensory ending, target, and background temperatures affect response. Using a target moving against a uniform background in a preliminary factorial experiment (body x target x background temperatures), we found response increased with target - background contrast. There was no response to varying absolute target temperature with fixed 6 °C contrast. But, contrary to nearly all other physiological processes, response increased as body temperature decreased. This response is integral to the facial pit sensory system, as we found the response to a moving visual target was independent of body temperature. We will describe the apparatus and present preliminary results of the resolution experiment.

54-5 BALCHAN, NR*; MACKESSY, SP; University of Northern Colorado; *neil.balchan@unco.edu*
Venom Resistance in an Eastern Colorado Rodent Community
The Red Queen hypothesis describes the coevolutionary dynamic between predator and prey where both partners must evolve in tandem to remain competitive. In several cases, rodents have demonstrated resistance to the venoms of their snake predators. For example, the California Ground Squirrel (*Otospermophilus beecheyi*) exhibits high resistance to the venom of the Pacific Rattlesnake (*Crotalus oreganus*). Conversely, cases exist where a prey species apparently lacks physiological resistance to the venom of its predator - the Cape Ground Squirrel (*Xerus inauris*) lacks venom resistance to the predatory Puffadder (*Bitis arietans*) and Snouted Cobra (*Naja annulifera*). My research evaluates patterns of venom resistance in a Colorado grassland ecosystem, where the Desert Massasauga (*Sistrurus tergeminus edwardsii*) and Prairie Rattlesnake (*Crotalus viridis*) predate upon a suite of rodent species. Field sites are located in northern (one snake predator) and southern Colorado (two snake predators) to investigate patterns of resistance between and within locations at the geographic level. Median lethal dose assays are used to assess venom resistance of select rodent populations to specific rattlesnake venoms. Serum-based assays determine the protective effect that a rodent's serum exhibits against specific venom components. Preliminary results indicate a moderate protective effect of the serum of Deer Mice (*Peromyscus maniculatus*) and Meadow Voles (*Microtus pennsylvanicus*) against Prairie Rattlesnake venoms, but not Desert Massasauga venom. Studying patterns of venom resistance in a system with two predator and multiple prey species allows us to understand better the evolution of such defenses and to evaluate whether local adaptation exists.

117-3 BALEBAIL, S*; SISNEROS, J A; University of Washington; *sujayb@uw.edu*
Relationship of advertisement call parameters with phenotypic traits in "singing" male plainfin midshipman
The plainfin midshipman (*Porichthys notatus*) is a vocal species of teleost fish that uses social acoustic signals for communication. During late spring and early summer midshipman migrate from deep water to the rocky intertidal region to breed. Type I or "singing" male midshipman construct nests beneath rocks and produce low frequency, long duration advertisement calls or "hums" to attract mates for spawning. Females locate nests via phonotaxis, lay their eggs in a single nest, and then return to deeper waters. Type I males care for the offspring until they are old enough to leave the nest. Field studies have demonstrated that larger males contain a greater number of offspring in their nests and laboratory two-choice experiments showed that females prefer to lay eggs in the nests of males with larger body size. We tested the hypothesis that male hums convey not only location but also fitness information to potential mates. We recorded the hum of eight captive male midshipman overnight in a tank maintained at a temperature between 12.8 – 14.4 °C and measured various call features such as the fundamental frequency (f0) and second harmonic (f1) of the hum, average call duration, and calling effort. We then correlated these quantities with potential indicators of male fitness such body length, body size, Fulton's body condition, gonad mass, and gonadosomatic index. Call duration and calling effort did not correlate with any of the morphometric parameters, but the fundamental frequency (f0) and second harmonic (f1) of the hum correlated positively with Fulton's body condition, but not with other parameters. Our preliminary data suggest the hum harmonics may serve as a condition-dependent or "honest" acoustic signal that provides important information related to the quality of the sender.

101-1 BALENGER, SL*; SIKKINK, K; ZUK, M; BAILEY, NW; University of Mississippi, University of Minnesota, St Andrews University; *balenger@olemiss.edu*
Fitness consequences and immunogenetic strategies against a novel parasitoid in a field cricket
Among the parasites of insects, endoparasitoids impose a unique challenge to host defenses because they use the body of another insect for the development and maturation of their eggs and/or larvae. Tachinid flies are highly specialized acoustically-orienting parasitoids that release mobile larvae, which burrow into the host's body to feed. Larval feeding typically leads to host death. We investigated the possibility that coevolving *Teleogryllus oceanicus* field crickets employ post-infestation strategies to maximize survival when infested with the larvae of the parasitoid fly *Ormia ochracea*. Using crickets from the Hawaiian island of Kauai, where the parasitoid co-occurs, and crickets from the Cook Islands (Mangaia), where the parasitoid is absent, we evaluated fitness consequences of infestation by comparing feeding behavior, reproductive capacity, and survival of males experimentally infested with *O. ochracea* larvae. We also evaluated genetic mechanisms underlying host responses by comparing gene expression in crickets infested with fly larvae for different lengths of time against that of uninfested control crickets. We did find some evidence for population differences in fitness (spermatophore production) and survival (total survival time post-infestation), although in both cases significant population effects 1) were not associated with the slope of the response to different numbers of larvae and 2) only emerged from models containing body condition at one but not both time points evaluated. Patterns of gene expression similarly show some evidence of population differences in response to infestation, but we did not find evidence for consistent differences in genes associated with immunity or the stress response.

62-5 BALIGA, VB*; SZABO, I; ALTSHULER, DL; University of British Columbia, Vancouver, BC Canada; *vbaliga@zoology.ubc.ca*
Examining the evolution of range of motion helps resolve gaps between form and function in the avian wing
The vertebrate limb is a dynamic structure that often includes many endoskeletal elements yet has traditionally been analyzed via "static" measures of morphology such as length or mass. Can incorporating a structure's dynamic capabilities help explain apparent gaps between form and function? For example, studies have repeatedly found that across broad investigations of avian clades, the correspondence between wing shape and flight behaviors is coarse. The avian wing, however, is well-suited to trace the evolution of motion capability: by modulating wing shape via skeletal joints, birds generate and control forces to keep themselves aloft. We measured the three-dimensional movement capabilities of wings from cadavers of 61 bird species from 20 avian orders, spanning a wide range of body masses and flight behaviors. These cadaver measurements were coupled with high-speed video of *in vivo* wing usage in three focal species. Using a phylogenetic comparative framework, we found that various aspects of range of motion strongly associate with flight behavior and/or body mass. In contrast, wing shape bears little correspondence to either explanatory variable. The static morphological traits of the wing also exhibit high phylogenetic signal whereas range of motion traits show greater evolutionary lability. Collectively, these results suggest a new framework for understanding the evolution of the vertebrate skeleton: rather than static morphology, it may be emergent properties such as range of motion that are predominantly reshaped as behaviors and body size evolve.

34-8 BALLESTEROS, JA*; AHARON, S; GAINETT, G; ZERN, J; ZEHMS, PP; GAVISH-REGEV, E; SHARMA, PP; University of Wisconsin-Madison, The Hebrew University of Jerusalem; *ballesterosc@wisc.edu*
An Integrative Investigation Of Eye Loss In Levantine Arachnids
The unique adaptations of cave-dwelling organisms are one of the most fascinating examples of convergent evolution. The reduction or total loss of eyes is an example of the suite of adaptations exhibited by troglobitic animals. But in arachnids, the genetic mechanisms underpinning this iconic phenotype are virtually unexplored. The study system of this contribution consists of disjunct populations of two arachnid orders from Israel and Palestine. These display a wide phenotypic spectrum of eye size, ranging from the typical arrangement eyes to complete blindness. Here, we implemented RAD-Seq approach to characterize the evolutionary dynamics and species boundaries of the cave and surface populations. To identify retinal determination gene network (RDGN) members involved in the reduction/loss of eyes, we performed differential gene expression (DGE) analysis of embryos prior and subsequent to eye formation from blind and eye-bearing populations of a whip-spider (Amblypygi, *Charinus*). DGE analysis identified RDGN members that are highly expressed in the eye bearing and lowly expressed in the blind whip-spider (or vice versa); among those, we found eye patterning candidates whose expression has been well-characterized in spiders. As validation of the DGE, we interrogated the function of a high-ranking RDGN homolog in the spider *Parasteatoda tepidariorum* using RNAi. The resulting phenotypes from these assays show an array of phenotypes that mirror the reduction in eyes observed the cave adapted spiders of Israel. Together, the integration of these approaches is providing the first insights as to the developmental genetic basis of eye evolution in arachnids.

34-5 BALLOU, L*; ILIFFE, T; OLESEN, J; BRACKEN-GRISSOM, H; Texas AM University at Galveston, University of Copenhagen, Florida International University; *balloul@tamu.edu*
Molecular Phylogeny of Remipedia: Providing Preliminary Insights into the Evolution of Feeding across an Enigmatic Crustacean Group
Remipedes are a class of crustaceans that are found predominantly within submerged anchialine cave ecosystems. Due to the limited accessibility of these habitats, insight into the evolutionary history and feeding ecology of this group remains largely unknown. Three previous reports have developed interspecies phylogenies of Remipedia; however, the addition of recently discovered species and evidence of cryptic speciation warrants further investigation. The purpose of this research is to further elucidate the evolutionary relationships of species within Remipedia using morphological and molecular techniques. Three mitochondrial genes (CO1, 16S, Cytochrome B) and two nuclear genes (H3, 18S) have been amplified and sequenced from 150 remipede samples. Sequences will then be trimmed, aligned, and compared using GENEIOUS and IQTREE. In addition to molecular analyses, remipede mouthparts (mandibles, maxilla one and two, maxillipeds) were dissected and photographed using scanning electron microscopy. Remipedes exhibit highly distinctive mouthpart morphotypes at the family level which may suggest divergent feeding strategies across the Class. Mouthpart morphotypes will thus be traced across the molecular tree in order to identify potential patterns of feeding evolution.

10-6 BARDUA, C*; BON, M; FABRE, A-C; DAS, K; HERREL, A; STANLEY, EL; BLACKBURN, DC; GOSWAMI, A; NHM, London, MfN, Berlin, MNHN, Paris , FMNH, Florida; *carla.bardua.15@ucl.ac.uk*
Macroecology and Morphological Evolution of the Frog Skull
Anurans (frogs) are the most speciose lissamphibian clade, and they exhibit astonishing cranial diversity, creating a significant challenge for quantifying cranial morphology across the clade. Here we quantify anuran cranial morphology using high-density landmarks and semilandmarks for 173 anuran species sampling every extant anuran family. The complex morphology of the frog skull is represented by a total of 995 landmarks and semilandmarks across 15 cranial regions, making this the most comprehensive dataset of anuran cranial morphology to date, in terms of both taxonomic sampling and density of shape data. With these shape data we investigate ecological, developmental, phylogenetic and allometric influences on the morphology, evolutionary rate and disparity of each cranial region. Microhabitat use is a strong influence on morphology, evolutionary rate and disparity. Semi-fossorial, fossorial, and aquatic species are the most disparate and fastest-evolving, and this pattern is most evident for jaw suspensorium cranial regions. Fossorial and aquatic species occupy distinct regions of cranial morphospace, with fossorial species associated with dorsoventrally taller skulls. Developmental strategy, in contrast, exhibits either a non-significant, or a very weak, influence on morphology, evolutionary rate and disparity. However, ossification sequence timing significantly influences evolutionary rate and disparity across frogs, with later-ossifying bones significantly more disparate and faster-evolving than early-ossifying bones. Phylogeny and allometry are both significant influences on frog crania, and cranial modules are differentially influenced by phylogenetic, allometric, and ecological effects.

31-7 BARFIELD, SJ*; DAVIES, SW; MATZ, MV; University of Texas, Austin, Boston University, University of Texas, Austin ; *sbarfield@utexas.edu*

Co-recruitment of Relatives Leads to Emergence of Inbred Genetically Isolated Group within a Panmictic Population of a Broadcast-spawning Reef-Building Coral

Many broadly-dispersing marine taxa are species rich, show genetic heterogeneity on small spatial scales, and are locally adapted to various environmental conditions. How such genetic subdivisions can emerge despite apparent lack of barriers to genetic exchange continues to be the major paradox of evolution in the sea. One understudied process potentially contributing to genetic structuring in marine populations is variation in larval recruitment. Here, we report an unusual recruitment pattern in the broadcast-spawning coral species Acropora hyacinthus on Yap Island, Micronesia. Reduced representation genotyping of 281 individuals on this isolated reef system demonstrated island-wide panmixia but also a genetically divergent group of juveniles at one out of the four sites sampled, showing elevated inbreeding and familial relatedness, including two pairs of siblings. Notably, adult corals as well as the majority of juveniles at the same site belong to the panmictic gene pool, suggesting that representatives of the inbred lineage co-recruited from elsewhere and are at least partially reproductively isolated from the rest of the island population. Reproductive isolation is further supported by finding several distinct genomic regions of greatly reduced genetic diversity in the inbred lineage, encompassing genes involved in sperm-egg recognition and fertilization that may serve as reproductive barrier loci. We propose that co-recruitment of genetic relatives via cohesive dispersal, a process that was previously unrecognized in marine invertebrates with planktonic larval phase, can generate familial genetic structure on the background of general panmixia and might be important for the emergence of genetically distinct locally adapted ectomorphs and sympatric, cryptic species.

124-5 BARKHOUSE, JM*; NEWBREY, JL; NEWBREY, MG; Columbus State University; *barkhouse_jessica@columbusstate.edu*

Laying-Sequence Variation in the Yolk Carotenoids of Eastern Bluebirds

We are studying laying-sequence variation in yolk carotenoids and egg metrics of Eastern Bluebirds (*Sialia sialis*) breeding in Columbus, Georgia, USA. Carotenoids are fat-soluble yellow, orange, and red pigments that are synthesized by plants, algae, and photosynthetic bacteria. These pigments play important roles in immunostimulation, antioxidation, free radical scavenging, sexual signaling, color vision, and embryonic development in birds. We are using high performance liquid chromatography to identify and quantify the carotenoids in Eastern Bluebird egg yolks. Eastern Bluebirds are a particularly interesting study species because no prior research has investigated laying-sequence variation in the yolk carotenoids of the species. We found that the yolks contained -carotene, -cryptoxanthin, astaxanthin, lutein, and zeaxanthin, with lutein being the most highly concentrated carotenoid. Contrary to results reported for other Eastern Bluebird populations, we did not detect any significant differences in in the mass, length, or width of the eggs across the laying-sequence. Preliminary results show that total carotenoid concentrations decline across the laying sequence, suggesting that Eastern Bluebirds use a brood reduction strategy in carotenoid allocation.

48-6 BARNES, DK*; ALLEN, JD; William & Mary; *dbarnes@email.wm.edu*

Predator-induced plasticity across echinoderm life history stages

Marine invertebrates frequently exhibit complex life cycles, including major life history transitions that coincide with habitat changes. In many marine invertebrates, adults live on the bottom of the ocean (the benthos), and broadcast spawn their gametes into the water column, where fertilization occurs and they begin life drifting in the water column as planktonic embryos and larvae, eventually metamorphosing into juveniles and returning to the benthos at settlement. Morphological phenotypic plasticity in response to environmental cues, may be especially important for organisms with complex life histories. As echinoderm larvae approach settlement, waterborne cues from the benthos may provide information about the future juvenile habitat, permitting expression of phenotypes that may improve post-metamorphic survival and performance. Larvae are known to detect and respond to the composition of the benthos when selecting settlement sites, but little is known about how benthic predator cues received by larvae affect juvenile phenotypes. We tested whether cues from a predator in a future habitat (the benthos) can be perceived by echinoderm larvae in their current habitat (the plankton) and modify juvenile phenotypes as they settle to the benthos. Larvae of *Dendraster excentricus* and *Strongylocentrotus droebachiensis* were exposed to predatory crab cues once juvenile rudiment formation began. *S. droebachiensis* exposed to crab cues as larvae had significantly more juvenile spines at settlement than those not exposed to the cue; however, there was no significant difference in spine length, disk area, or age at settlement. In contrast, *D. excentricus* larvae exhibited earlier settlement when introduced to a crab cue. These results suggest that planktonic larvae are capable of responding to benthic cues, but those responses may vary among species.

2-8 BARTS, N*; GREENWAY, R; HENPITA, C; ARNDT, S; SHAW, J; KELLEY, J; TOBLER, M; Kansas State University, Oklahoma State University, University of Cambridge, Oklahoma State University , Washington State University; *barts2@ksu.edu*

Repeated mitochondrial evolution underlies adaptation to extreme environments

Extreme environments are characterized by harsh physiochemical stressors that push organisms to their physiological limits. Despite the challenges presented by these habitats, life can be found thriving in nearly every example of extreme environment. The question remains whether or not organisms inhabiting similar extreme conditions evolve in similar ways. To test for these, we investigated the mechanisms that facilitate adaptation to hydrogen-sulfide (H2S), a potent respiratory toxicant that directly interferes with mitochondrial function, in evolutionary independent lineages of poecilids, with special emphasis on populations of *Poecilia mexicana*. Analysis of gene expression across sulfide-tolerant and -intolerant poecilids shows that H2S tolerance is potentially mediated by convergent modification and expression of genes involved in H2S toxicity and detoxification. The primary pathways associated with H2S tolerance were oxidative phosphorylation (OxPhos) and H2S detoxificatiom initiated by the sulfide:quinone oxidoreductase (SQR) pathway. We assessed function of OxPhos enzymes and SQR in response to H2S in three lineages of *P. mexicana* and show that sulfide-tolerant populations maintain higher OxPhos activity and have higher SQR activity compared to sulfide-intolerant fish. We also found evidence for increased regulation of internal H2S concentrations in sulfide-tolerant fish. Together, these pathways appear to be responsible for the maintenance of mitochondrial respiration rates in sulfide fish even when H2S is present. Our results indicate that convergent adaptations in mitochondrial processes facilitate the colonization of extreme H2S-rich habitats.

45-7 BASS, AH; BASS, And; Cornell University, UC Bodega Marine Laboratory; *ahb3@cornell.edu*
Behavioral Timing: The Essential Role of Neurohormonal Mechanisms
Field studies of animals behaving in their natural habitat provide an essential context for framing questions related to the evolution of daily and seasonal changes in social behavior. How the timing of such events on multiple timescales ranging from milliseconds to hours is determined by neurohormonal mechanisms remains largely unexplored. Studies of circulating hormones, like those led by Rosemary Knapp, are a cornerstone of all such investigations. How might we use such foundational information to identify the contribution of cellular and molecular mechanisms determining this form of adult plasticity? This and related questions will be addressed largely by focusing on recent evidence from studies of one particular group of aquatic vertebrates commonly known as toadfishes that exhibit alternative reproductive tactics and depend upon acoustic communication for their reproductive success. Research support from NSF IOS-1656664 and 1457108.

117-1 BASTIAANS, E*; JAVALY, N; O'LOUGHLIN, C; MCCORMICK, L; WEGRZYN, P; SUNY Oneonta, Portland State University; *elizabeth.bastiaans@oneonta.edu*
Can I Buy You a Drink? The Effect of Male Hydration Status on Male Mating Behavior and Female Life History in Bean Beetles
Individuals are expected to alter their reproductive tactics in response to variation in available resources. The bean beetle, *Callosobruchus maculatus*, is an ideal model for understanding how variation in resource availability affects reproductive behavior. Adults typically do not eat or drink after pupation, but they will consume water if given the opportunity. Also, male bean beetles have barbed intromittent organs that harm females during mating. Despite this cost, female bean beetles often mate multiply, even when males are prevented from harassing them. Previous work suggested that females may derive hydration benefits from male ejaculate transferred during mating, because females given access to water mated less frequently than females not given access to water. We asked whether water access would also affect male mating behavior or the reproductive success of females mated to well-hydrated vs. dehydrated males. We tested whether males given access to water transferred larger ejaculates, copulated for longer periods of time, or exhibited a stronger preference for virgin female mates than males not given access to water. We also tested whether females mated to these two categories of males differed in post-mating lifespan, fecundity, or egg viability. We found that males were more likely to copulate with virgin female beetles than with non-virgins, although they copulated with non-virgin females for longer. Hydration status did not affect the strength of males' preference for virgins. Females mated to hydrated males did not live longer than females mated to dehydrated males, but they exhibited slightly higher fecundity and higher egg viability.

S10-3 BATTISTA, NA; The College of New Jersey; *battistn@tcnj.edu*
Fluid-structure interaction for the people!
Hearts, jellyfish, seagrass, and general squishy things all have something in common - they all involve fluid-structure interactions (FSI). FSI applications are numerous and vital in many fields across science and engineering. While there exist robust methods for investigating FSI, many necessitate the use of complex computer simulations. The knowledge of how to carry out out such simulations creates a barrier that has made this traditionally under-utilized and inaccessible by researchers, particularly students. *IB2d* ("I beg to differ") is open source software that was specifically designed to make FSI accessible to the scientific community and student researchers. During this talk, I will highlight some standard approaches in FSI across a variety of applications, including biomechanics and biomimetic devices.

S5-2 BAUER, U; University of Bristol; *ulrike.bauer@bristol.ac.uk*
Functional Surfaces of Insect-trapping Pitcher Plants
Pitcher plants do not just solve physical problems – they *use* physics to solve one of the most existential problems in nature: finding food. Every single part of their pitfall traps is adapted to make the most of gravity. Anti-adhesive wax crystals line the inside of the trap. The collar-shaped trap rim is decorated with an elaborate pattern of microscopic ridges, grooves and steps, and turns into a deadly slide for insects when it is wetted by rain or dew. In some species, even the roof-like pitcher lid is modified into a rain-powered springboard that catapults insects into the fluid-filled trap below. The diversity and high level of perfection of their anti-adhesive surfaces means that pitcher plants have become a model for biomechanical research and an inspiration for the development of biomimetic functional surfaces. This talk summarizes the current state of research and gives an outlook on open questions and future directions.

72-6 BAUMGART, SL*; CLAESSENS, LPA; University of Chicago, Maastricht University; *slbaumgart@uchicago.edu*
Avian sternum disparity and ecomorphological implications
The avian sternum anchors the main muscles powering flight and is highly disparate in morphology. For instance, some birds feature long, narrow sternal plates with deep keels, others have almost square sternal plates and shallow keels, and some have very reduced or non-existent keels. Little work has focused on the relationship between the complex sternum shape and a bird's ecomorphology. Here, we use automated three-dimensional (3D) geometric morphometrics (auto3dgm in Matlab) on a sample of 124 isolated avian sterna to examine relationships between sternal form and function. The R package Geomorph was used to run a General Procrustes Analysis and a Principle Component (PC) Analysis to examine the sternal plate disparity across Aves. In our results, PC1 ranges between a square sternal plate and a shallow keel (e.g., owls, grebes) and a long, narrow sternal plate with a deep keel (e.g., turkeys and doves). PC2 ranges between a posteroventrally-inclined leading edge of the sternal keel (e.g., owls, turkeys) and an anteroventrally-inclined leading edge of the sternal keel (e.g., gannets, loons). PC3 ranges between an angled posterolateral margin (e.g., tropicbird, hornbill) and a rounded posterolateral margin (e.g., loons, kakapo). A 3D plot of these PCs shows that phylogeny seems to be the predominant factor driving most of the clustering in the analyses. Owls group together, pheasants and turkeys group together, and ducks and geese group together. However, convergence is also evident; for example, a cluster with doves, macaws, and terns exhibits very deep keels extending the full length of an anteroposteriorly elongate sternal plate. These observations suggest that certain sternum morphologies can be used for multiple behaviors and habitats and that sternal shape is not driven by phylogenetic relationships alone.

55-2 BEATTY, AE*; SCHWARTZ, TS; Auburn University; *aeb0084@auburn.edu*
We need to talk...about IGF2: A cross-species comparison of IGF1 and IGF2 expression in amniotes.
The Insulin and Insulin-like Signaling (IIS) network regulates cellular processes including growth, reproduction, and longevity. The top regulators of signaling in this network are the paralogous hormones IGF1 and IGF2. In mice and rats, IGF2 expression is turned off soon after birth, while IGF1 remains on throughout life. However, this is different from the expression patterns in humans and recent studies in reptiles that demonstrate IGF2 expression continues through adulthood. The lack of postnatal IGF2 expression in lab rodents has led to the hormone's physiological effects and regulation of the IIS network during adulthood to be ignored. To test the extent to which IGF2 is expressed postnatally in amniotes, we quantify the gene expression of the IGF1 and IGF2 hormones across amniote lineages using two approaches. First we use quantitative PCR on liver cDNA at three life stages (embryonic, juvenile, and adulthood) to compare the expression of IGF1 and IGF2 across the lab reared house mouse, wild derived house mouse, wild deer mouse, zebra finch, house sparrow, eastern fence lizard, and brown anole lizard. Second, we mine adult liver transcriptomes for all amniotes that are publicly available in NCBI and quantify relative expression of IGF1 and IGF2. In contrast to the biomedical models, we find that IGF2 is expressed ubiquitously across adult sauropsids and in many mammals, often at a higher level than IGF1. These data provide a fundamental understanding of IGF2 expression patterns in amniotes and in doing so has identified a spotlighting effect bias due to the acceptance of knowledge from laboratory rodents as being the default. Further, we identify species that can be used to study the function of IGF2 across lifespan.

41-4 BECKER, DJ*; SCHULTZ, EM; ATWELL, JW; HALL, RJ; KETTERSON, ED; Indiana University, Wittenberg University, University of Georgia; *danbeck@iu.edu*
Urban residency, host immunity, and infectious disease dynamics in a traditionally migratory songbird
Human-induced changes to climate and habitat (e.g., urbanization) can facilitate traditionally migratory animals becoming year-round residents. As migration can be energetically expensive, shifts to sedentary behavior may minimize energy demands from long-distance movements and their immunosuppressive effects. Residency in urban habitats could further minimize energetic demands owing to abundant food resources and allow sedentary animals to invest more in immunity. To examine how recent shifts to residency affects physiology in ways that may shape disease dynamics, we analyzed leukocyte profiles of two dark-eyed junco (Junco hyemalis) populations in southern California: the Laguna Mountain population, which breeds in high-elevation forests and migrates altitudinally, and the urban San Diego population, which was likely established by overwintering migrants in the 1980s and has become non-migratory. Over a two-year study of each population's breeding season in 2006 and 2007, we found no difference in the ratios of heterophils to lymphocytes between populations, suggesting similar baseline glucocorticoid levels. However, urban residents had higher total leukocytes than migrants, together suggesting minimal differences in energetic demands between populations. However, urban residency may confer immunological benefits through abundant anthropogenic resources. To explore the epidemiological consequences of such benefits, we outline a susceptible–infected–latent–infected modeling framework that couples migrant–resident interactions and their respective annual cycles. By varying the strength by which urban habitats modify host resistance and competence of residents, alongside migration-induced relapse, we show how these individual-level changes can scale up to shape population-level infection dynamics.

48-4 BEDGOOD, SA*; BRACKEN, MES; University of California Irvine; *sbedgood@uci.edu*
Making it Big and Losing Friends: Algal Symbiont Contributions are Shaped by Sea Anemone Life History
The stability of nutrient exchange in a mutualistic symbiosis is highly dependent on the availability of resources to both partners, and interactions between partners can shape niche partitioning among holobionts. Symbiotic sea anemones on California rocky shores obtain nitrogen and carbon from prey that they capture, but a large portion of their dietary carbon comes from contributions by symbiotic dinoflagellate algae in the family Symbiodiniaceae. We hypothesize that life history traits including allometry, surface-area-to-volume ratios, and reproductive strategies affect the potential for contributions from the algal symbionts. Our approach includes both observational and experimental studies of three congeneric sea anemone species. *Anthopleura xanthogrammica* is the largest species, *A. sola* is smaller, and *A. elegantissima* is the smallest, reproducing asexually to create large clonal mats. We designed an in situ experiment where the diets of sea anemones were manipulated by either adding or removing prey daily for three weeks. Tissue samples of sea anemone, algal symbiont, and common prey items were collected from the experiment and from an adjacent site for carbon and nitrogen stable isotope analysis. The ^{15}N values suggest that the diets of sea anemone species are different even though the anemones are found in the same habitat. The ^{13}C values are similar between *A. sola* and *A. xanthogrammica* but both are different from *A. elegantissima* values. We found that ^{13}C values of *A. elegantissima* anemone tissue and associated algal symbionts closely match while *A. sola* and *A. xanthogrammica* anemone tissue and algal symbiont ^{13}C do not match. This suggests that *A. elegantissima* relies mostly on algal symbiont contributions for its dietary carbon intake while *A. sola* and *A. xanthogrammica* receive a larger portion of their dietary carbon from heterotrophic feeding.

31-5 BEDWELL, H*; BAY, L; FULLER, Z; PRZEWORSKI, M; MATZ, M; University of Texas at Austin, Austin, Texas, Australian Institute of Marine Science, Columbia University, New York City, NY, Columbia University, New York City, NY; *hbedwell@utexas.edu*

Mitochondrial introgression and its role in coral thermal tolerance

Increasingly frequent thermal stress events are causing strong selection for higher thermal tolerance in corals. While most studies have focused on thermal tolerance associated with the coral's symbiotic algae, a recent study shows the larval thermal tolerance of *Acropora millepora* depends on maternal background, suggesting mitochondrial (mt) variation might also play an important role in coral thermal tolerance. To assess mt variation, 225 individuals were sampled throughout the mid-range of the Great Barrier Reef (GBR). DNA was extracted and individuals were genotyped using whole-genome resequencing. There are two mt haplotypes, and mt genome alignments of 12 acroporid species suggests one of the haplotypes is introgressed from another species. Both mt haplotypes are found at high frequencies in populations across the mid-GBR. However, it is unclear whether mt haplotype frequencies correspond with local thermal regimes, as samples do not span the entire 3°C thermal range of the GBR. To assess whether there are mitonuclear interactions associated with the haplotypes, larvae were obtained by crossing *A. millepora* adults with different mt haplotypes, thus crosses share the same nuclear background, but differ in their mitochondria. For each cross, ~2,000 larvae were reared at 28°C, as a control, and at 36°C, as a heat selection treatment. DNA samples were taken when only 25% of the larvae remained in the 36°C heat selection treatment. The survivors of the heat selection treatment and the unselected larval pools were sequenced, and bulk genotyped using 2b-RAD. If the two mt haplotypes result in different genomic loci responding to heat selection, this suggests mitonuclear interactions play a role in coral thermal tolerance.

85-3 BEERY, SM*; OLSON, RA; MONTUELLE, SJ; WILLIAMS, SH; Ohio University, Ohio University Heritage College of Osteopathic Medicine, Ohio University Heritage College of Osteopathic Medicine; *sb633118@ohio.edu*

Effect of food properties on molar occlusion during chewing in pigs

A fundamental component of mammalian feeding is mastication, involving occlusion of postcanine teeth to finely break down food into smaller particles. The dynamics of occlusion have primarily been inferred from surface features of the teeth, including occlusal topography and wear patterns. Recently, however, X-Ray Reconstruction of Moving Morphology (XROMM) provides the visualizing and measurement resolution necessary to characterize the dynamics of occlusion during chewing. Here, we use XROMM to investigate the effect of two food properties, stiffness and toughness, on molar occlusion during rhythmic chewing in pigs. Four pigs were fed size standardized pieces of apple (low toughness and low stiffness), carrot (high toughness and low stiffness), and almond (high toughness and high stiffness). We compared the duration of the occlusal period as well as the translations in the buccolingual, mesiodistal, and ventral-dorsal planes of individual cusps. Mixed effects modeling with repeated measures on individuals demonstrated that toughness and stiffness differentially impact occlusal dynamics. Increasing food toughness results in longer tooth-food-tooth or tooth-tooth contact during chewing, but there was no change associated with increased food stiffness. Translations of the first molar were observed in the mesiodistal plane across foods of different toughness while buccolingual displacements were different among foods of different stiffness. These results may reflect that low toughness foods require less tooth-food-tooth contact to facilitate bolus creation, whereas foods of different stiffness impact other measures of the gape cycle (i.e., translations).

21-4 BEHBAHANI, AH*; RAK, AK; SKUTT-KAKARIA, KJ; DICKINSON, MH; California Institute of Technology; *amirhb@caltech.edu*

Flies Remember Multiple Food Locations in the Absence of External Cues

The fruit fly, *Drosophila*, has an extensive repertoire of behaviors generated by a brain with only 100,000 neurons, which suggests remarkably low computational complexity. One essential behavior is foraging, which is complicated by the fact that food is variable in quality and patchy in distribution. One strategy that flies use to adapt to patchy and variable food environments is to execute a local search once they initially find food. During this local search, flies exhibit path integration; that is, they keep an internal memory of the location of the initial food patch. Path integration is arguably one of the most sophisticated tasks performed during locomotion and is thought to depend on the function of the Central Complex (CX), a set of unpaired nuclei in the core of the insect brain. Our lab recently showed that local search can be induced by an optogenetic stimulus in lieu of actual food. Using this paradigm, we can make flies perform local search in a constrained arena, such as a narrow circular channel. Using this fictive food within this simplified, one dimensional arena, we studied whether flies remember more than one food location. When we presented one or two fictive food sites, we found that fly's search behavior is biased toward food locations it previously encountered. We propose that when multiple foods are present, flies use the specific spacing of the food sites to update their search range to include all the food sites they have experienced. As the fly cannot see and must rely on an internal representation of distance, these experiments help provide compelling evidence of how spatial distributions may be encoded in the insect brain and future studies will be critical in determining whether the CX is involved in these functions.

22-4 BENSKY, MK*; BELL, AM; University of Illinois Urbana-Champaign; *bensky2@illinois.edu*

The evolution of cognition and behavior during a natural biological invasion

Species invasions provide an opportunity to study how traits evolve as organisms move into novel environments. The invasion process might act as a filter either via nonrandom dispersal and/or selection, thereby leading to phenotypic differences between the invading and source populations. Here we test the hypothesis that behavior and cognition facilitate the invasion process by comparing natural variation in behavior among genetically-differentiated populations of threespined stickleback that were reared in a common garden. Specifically, we compared sticklebacks from two populations from the ancestral source marine environment to sticklebacks from four freshwater lakes that differ in time since establishment. If increased neophilia and inhibitory control are beneficial for colonizing new environments, and thus evolve over the course of a biological invasion, then we predicted that derived freshwater populations would be more neophilic and exhibit higher levels of inhibitory control (i.e. more likely to abandon a behavior pattern that is no longer effective) compared to sticklebacks from the ancestral source population. We observed substantial variation in both traits among populations, and found support for our hypothesis: well-established freshwater populations were more neophilic and had higher inhibitory control than marine fish. Differences between very recently derived freshwater populations suggest that these differences can evolve rapidly, though nonrandom dispersal cannot be excluded as a potential explanation. These findings are consistent with the hypothesis that cognitive traits have played an important role in allowing stickleback to successfully colonize freshwater habitats, and that these traits have evolved during the invasion process.

56-8 BENSON, BE; AICHELMAN, HE; BAUMANN, JH; NIEVES, OC; STANIZZI, DA; CASTILLO, KD; DAVIES, SW*; Boston University, UNC CH, UNC CH; *daviessw@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 coral bleaching. Predictions about the likelihood of coral bleaching typically consider the duration and magnitude of elevated temperatures relative to a locally defined threshold. However, recent work suggests that heterogeneity in observed bleaching patterns may be better explained by the degree of diel thermal variation (DTV) experienced on a reef. Here, we sourced colonies of the reef-building coral *Siderastrea siderea* from six sites across the Bocas del Toro archipelago, which ranged in mean DTV (~2-4 °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) on growth and performance of *S. siderea* and then performed a two-week thermal challenge followed by a two-week recovery. Results suggest that corals sourced from higher DTV sites outperformed corals from less variable sites, regardless of treatment. In addition, experimental DTV had a positive influence on corals, with high DTV leading to increased growth and corals experiencing moderate DTV maintained higher symbiont densities after recovery. Analyses of baseline and post-recovery physiological traits as well as baseline algal and microbiome community compositions are ongoing. These analyses will shed light on how corals from higher DTV environments are able to maintain higher growth rates and how DTV modulates coral stress and ultimate recovery. Overall, our data support the hypothesis that DTV on the coral's native reef and in husbandry conditions 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.

18-3 BENTZ, AB*; GEORGE, EM; WOLF, SE; RUSCH, DB; BUECHLEIN, A; ROSVALL, KA; Indiana University; *bentza@iu.edu*

Immediate and lasting neurogenomic responses to competition in a free-living songbird: an experimental manipulation of a dynamic social environment

Periods of social instability can elicit pronounced changes in behavior and adaptive re-allocation of resources to promote success in future competition. However, the molecular mechanisms underlying this phenotypic plasticity are unclear in the natural and dynamic social environments faced by free-living animals. Here, we experimentally generated intense social instability for a wild, cavity-nesting female songbird (tree swallows, *Tachycineta bicolor*). We reduced nest box availability after initial settlement, generating heightened competition; 24hr later, we returned boxes, causing aggressive interactions to subside. We collected females during the peak of competition and after it had ended, along with date-matched controls. We measured transcriptomic responses in two behaviorally relevant brain regions, the hypothalamus and ventromedial telencephalon. Gene set enrichment and network analyses suggest processes related to energy mobilization were upregulated during and after competition, while sensory perception and hormone processing were not upregulated until after competition had ended. Immune-related gene regulation was more complex, with lymphocyte processes downregulated during competition and antigen presentation upregulated after competition. Our data also hint at epigenetic mechanisms that may mediate the lasting effects of competition. By experimentally manipulating competition in the wild, these data collectively show how natural social instability causes shifts in gene expression that may facilitate the demands of competition at the expense of self-maintenance. Further, some of these effects persist after competition has ended, suggesting individuals may be "primed" for success in future social instability.

S8-6 BERGMANN, P.J.*; MANN, S.D.W.; MORINAGA, G.; FREITAS, E.S.; SILER, C.D.; Clark University, Oklahoma State University, University of Oklahoma; *pbergmann@clarku.edu*

Convergent evolution of vertebral morphology and locomotion in snake-like lizards

Snake-like body forms have evolved convergently dozens of times in most major lineages of vertebrates. Despite studies of various clades with snake-like species, we still lack an understanding of their evolutionary dynamics and distribution on the vertebrate tree of life. We also do not know whether this convergence in body form coincides with convergence at other biological levels. Here, we present the first vertebrate-wide analysis of how many times snake-like forms have evolved, as well as rates of its evolution and reversion to a non-snake-like form. We then focus on five examples of snake-like form evolution in squamates and test if they are convergent in vertebral number and shape, as well as their surface locomotor performance and kinematics. We do this by comparing each snake-like species to closely related tetrapodal species and determining whether the direction of vertebral or locomotor change matched in each case. The five lineages examined are obscure, rare species that live in remote locations, providing a valuable glimpse into their biology. They are the skink lizards *Brachymeles lukbani, Lerista praepedita*, and *Isopachys anguinoides*, the basal squamate *Dibamus novaeguineae*, and the basal snake *Malayotyphlops cf. ruficaudus*. Our results support convergence among these species in the number of trunk and caudal vertebrae, and in vertebral aspect ratios, but not relative vertebrae length. We also find that the snake-like species are relatively slower than their limbed counterparts, with the exception of *Malayotyphlops*, and move with lower frequency and higher amplitude body undulations. This is among the first evidence of locomotor convergence across distantly related, snake-like species.

52-6 BERLOW, M*; PHILLIPS, JN; DERRYBERRY, EP; University of Tennessee, Knoxville, California Polytechnic State University; *mae.berlow@gmail.com*

Effects of Urbanization and Landscape on Wild Avian Gut Microbiomes

The rapid effects of human land development present relatively recent and stark changes in the environment. Recent work in birds and humans suggests that urbanization may affect the composition of animal gut microbiomes. Factors driving observed differences between urban and rural gut microbiomes are unknown, but may include diet, geography, and/or pollution. To better understand these effects, we investigated the relationship between urbanization and the gut bacterial community of white-crowned sparrow populations in the San Francisco Bay area. We addressed three questions: 1) Which aspects of a bird's environment influence their gut bacterial community? 2) Which host morphological characteristics best explain gut bacterial community? 3) Are these morphological characteristics mediating the relationship between host environment and gut bacterial community? We also assessed the effects of urbanization by examining the taxonomic composition of gut bacterial communities in birds across habitats. We find direct effects of environmental factors, including urban noise levels and territory land cover, as well as indirect effects through body size and condition, on alpha and beta diversity of gut microbial communities. Elucidating these effects provides a better understanding of how urbanization affects wild avian physiology.

109-1 BERTUCCI, EM*; PARROTT, BB; University of Georgia, Athens, GA; *emily.bertucci@uga.edu*
Characterization of the Age-Related DNA Methylome and Development of an Epigenetic Age Predictor in Medaka (Oryzias latipes)
Age specific patterning of DNA methylation ("epigenetic aging") is the single best marker of biological age as it is strongly correlated with chronological age, the onset of age-related disease, and all-cause mortality. Epigenetic age predictors use loci specific changes in the status of DNA methylation across the genome to predict chronological age with astonishing accuracy. Discrepancies between chronological and epigenetic or "biological" age can be used to explore the molecular underpinnings that determine different aging trajectories. Further, important life history characteristics such as the onset of reproductive maturity and senescence are associated with epigenetic age, suggesting that accelerated epigenetic aging may have implications on the timing of ecologically important life history events. We aimed to identify and describe the age-related DNA methylome and develop an epigenetic clock for a model fish species, medaka (*Oryzias latipes*), using reduced representation bisulfite sequencing of 2-, 6-, and 12-month old animals. Our findings suggest that a substantial portion of methylation changes correlate with chronological age, with a greater proportion of change occurring early in life relative to late. Using just 39 of these age-associated loci, we have developed a model that is highly predictive of chronological age (cor = 0.9495) and provides the ability to assess biological age acceleration in the response to environmental factors. Here, we present preliminary tests for age acceleration and provide a characterization of the age-related loci which demonstrates the genomic distribution and functional associations of the age-related methylome. Our results contribute towards ongoing research attempting to elucidate the functional role of DNA methylation in aging.

S3-9 BHULLAR, B.-A.S.*; MANAFZADEH, A.R.; MIYAMAE, J.A.; HOFFMAN, E.A.; BRAINERD, E.L.; MUSINSKY, C.; CROMPTON, A.W.; Yale University, Brown U niversity, American Museum of Natural History, Brown University, Harvard University; *bhart-anjan.bhullar@yale.edu*
The origin of chewing in mammals required rolling of the jaw and involved broad continuity in molar form and function
Recently, we used a combination of 3D x-ray reconstruction of moving morphology (XROMM) and comparative analysis of fossil and extant anatomy to argue that the unique mammalian food processing system originally required independent rolling of unfused hemimandibles. Moreover, the original function of the therian tribosphenic molar was to grind food in a reverse mortar-and-pestle arrangement by which the talonid "mortar" moved transversely across the protocone "pestle." This transverse motion was enacted primarily by long-axis jaw rotation. Primitive therian mammals including opossums (Monodelphis domestica) retain the ancestral mode of chewing, including the mortar-and-pestle rotational grinding stroke. Here we consider the experimental and comparative data further and show that jaw roll is broadly conserved across mammals, and that the rotational grinding stroke can be inferred to have been present at the therian ancestor -- probably, in fact, well down the therian stem. Fusion of the jaw symphysis has occurred repeatedly in omnivorous and herbivorous therian clades and is associated with low-crowned teeth and grinding by transverse motion of the mandible. It is also associated with reduction of the angular process, which we argue serves to provide greater leverage for jaw-rolling musculature. Finally, we suggest that there is greater continuity in molar structure and function on the stem of Theria than has previously been appreciated.

59-4 BIERLICH, KC*; DALE, JD; FRIEDLAENDER, AS; GOLDBOGEN, JA; JOHNSTON, DJ; Duke University, University of California, Santa Cruz, Stanford University; *kcb43@duke.edu*
Dwarf minke whales along the Antarctic Peninsula: Evidence of climate migration or historic misidentification?
The global distribution of dwarf minke whales (*Balaenoptera acutorostra subspecies*) is poorly understood, but it appears they tend to occupy low latitude waters off the coasts of Brazil, South Africa, and Australia, and occasionally in the South Indian Ocean. In March 2019, we encountered dwarf minke whales (n = 5) along the South Shetland Islands (SSI), identified post-encounter through unoccupied aerial system (UAS) photogrammetry and resulting morphological and phenotypical comparison between Antarctic minke whales around the Western Antarctic Peninsula (WAP) (n = 40). The only published study documenting dwarf minke whales along the WAP and SSI includes 11 sightings from 2007-2010, suggesting they are rare and only recently encountered in this region. One possible explanation for the paucity of sightings in this region is a southward range expansion concurrent with regional warming and ecosystem forcing that has facilitated southward range expansions of other sub-Antarctic species. This hypothesis is supported by ongoing changes in the distribution and abundance of myctophid fishes, an important prey item of dwarf minke whales. Alternatively, they may have always been present along the WAP and SSI, but have been misidentified as Antarctic minke whales, as these two species are difficult to distinguish from one another, especially from boat-based surveys. UAS photogrammetry provides opportunity to view these animals in high-resolution to distinguish subtle differences in morphology and phenotype. This study quantifies phenotypic differences between dwarf and Antarctic minke whales, and compares them to other Southern Hemisphere populations, setting a foundation to effectively test these two competing hypotheses related to southward range expansions or historic misidentification.

26-3 BILAK, JD*; WHILES, MR; MILANOVICH, JR; BYSTRIANSKY, JS; WARNE, RW; Southern Illinois University, Carbondale, IL; Daniel P. Haerther Center for Conservation and Research, Shedd Aquarium, Chicago, IL.; *bilak@siu.edu*
Understanding the physiological mechanisms causing seasonal movement changes in common mudpuppies.
The common mudpuppy (Necturus maculosus) was once common in temperature lakes of North America, however, very little is known of their current population status or basic natural history, including seasonal movements. Intriguingly, these ectotherms appear to exhibit inverse seasonal activity patterns, increasing activity during the winter months. The physiological and ecological factors determining these patterns are poorly understood. While metabolic adaptations likely play a role, we suspect reproductive and foraging ecology are also central determinants of these seasonal activity patterns. In collaboration with the Shedd Aquarium veterinary staff, we implanted radio-telemetry transmitters in 27 mudpuppies between March and December 2017, at Wolf Lake in Chicago, IL. Mudpuppies were located every ~16 days from April 2017 – July 2018. Farthest movements were correlated with water temperature increases during March 2017 – December 2017, but not during December 2017 – July 2018. In addition to seasonal movements, we measured water-borne reproductive hormone metabolites and temperature dependent metabolism in captive animals. Increased encounters (captures and sightings) during colder temperatures may indicate mate searching or higher energy demands in preparation for ovulation and egg laying, as mudpuppies breed in late fall to early spring. Higher activity in the winter may be linked to increased catchability of fish or decreased seasonal predation. Temperature dependent metabolism suggests adaptations related to winter reproduction or foraging. Increasing our understanding of the mechanisms underlying seasonal movements and habitat selection of this distinctive salamander will facilitate conservation efforts in a changing climate.

89-3 BILLAH, MM*; RAHMAN, MS; University of Texas Rio Grande Valley; *mohammad.billah01@utrgv.edu*

Detection and Enumeration of Bacterial Pathogens in the American Oyster, Crassostrea virginica

American oyster (*Crassostrea virginica*) is a popular sea food for its delicacy and high nutritional value. Based on increasing concern about bacterial pathogen contamination in shellfish, our research objectives have been focused on detection, enumeration and comparison of two important microbial pathogens, *Escherichia coli* and *Salmonella* spp. proliferation in the American oyster in south Texas waters and controlled laboratory studies. Immunohistochemical analysis showed substantial bacterial pathogen's presence in gill and digestive glands in oysters collected from San Martin Lake (SML) compared to South Padre Island (SPI). Extrapallial fluid (EPF, an important body fluid) glucose levels, pH, and protein concentrations were significantly higher in oysters collected from SML compared to SPI. Laboratory studies showed increasing trend of bacterial pathogens with elevated temperatures (28 and 32°C) compared to control (24°C). EPF pH and protein concentrations were increased, however, EPF glucose levels were decreased with higher temperatures compared to control. Collectively, immunohistochemical analysis together with EPF pH, glucose levels, and protein concentrations results suggest that American oyster is prone to water-borne pathogen contamination in south Texas waters and increasing global temperature induces pathogen proliferation as well.

83-1 BILOTTA, F*; LEE, M; DANOS, N; University of San Diego; *ndanos@sandiego.edu*

Pregnancy-induced changes to muscle-tendon morphology and function

Live bearing is a defining feature of all eutherian mammals. In order to accommodate the fetus, the female body undergoes radical hormonal, morphological and mechanical changes. Yet, we know very little about the effects of pregnancy on skeletal muscle-tendon units and the whole organism. We used the gastrocnemius muscle of rats as a model system to examine the organ and whole animal level effects of pregnancy, by comparing animals that had never been pregnant, primiparous animals near the end of pregnancy, and postpartum animals. We found that muscle mass did not change significantly with pregnancy, even though pregnant animals were approximately 30% heavier than non-pregnant ones. However, in postpartum animals muscle mass was reduced by 22%. Muscle fiber size did not vary among conditions but postpartum animals were the only ones with muscle fibers larger than 0.20 mm². We predicted that muscle vascularization would increase with pregnancy due to the action of the hormone relaxin. Preliminary histological data support our prediction. Since relaxin is also an antifibrotic agent, we predicted that it would affect the mechanical properties of collagenous tissues associated with muscle. The stiffness of the proximal aponeurosis of the lateral gastrocnemius, as measured by the tangent slope at strain=0.13, did not vary by condition. Interestingly, there was high variation in all conditions. All females tended to have lower Achilles tendon stiffness than males, although this was not statistically significant. However, tendon stiffness had surprisingly low variability in the postpartum animals that was highly significant ($P < 0.001$). Ongoing videographic analysis in our laboratory is characterizing the gait of animals as they perform a demanding task (20% incline) to examine the effects of pregnancy on the whole body.

S11-11 BINGMAN, V P; Bowling Green State University, Ohio; *vbingma@bgsu.edu*

Avian Spatial Navigation and the Hippocampus: Can Diversity in Behavioral Mechanisms Guide Searches for a Genetics of Cognition?

Among the various forms of vertebrate cognition, spatial cognition and navigation appear universally dependent on the hippocampus of all tetrapods and possibly teleost fish as well. Co-occurring with this general uniformity are differences in the hippocampal-dependent representation of space among vertebrate groups that presumably reflect adaptive variation. Yet surprisingly, little is known about how variation in the organization and function of the hippocampus in different vertebrate groups can be explained by genetic variation. Here patterns of developmental gene expression may be informative. Independent of the hippocampus, there has been some success in identifying genetic correlates of the specialized migratory, but not navigational, behavior of birds and electroreception in elasmobranchs; findings that have some implication for understanding genetic influences on varying spatial abilities. Nonetheless, these examples are remote from cognition and one has to wonder if the search for genetic correlates of varying spatial cognitive abilities in animals can overcome experimental obstacles, not the least of which is obtaining the sufficiently large subject pools needed to detect the certain small effect sizes of single genes.

99-4 BIONDI, AA*; AMPLO, HE; CRAWFORD, CH; BEMIS, KE; FLAMMANG, BE; New Jersey Institute of Technology, Virginia Institute of Marine Science; *aab53@njit.edu*

Adventures in scaling and remodeled morphology: the case of the Ocean Sunfish

Mola mola (Ocean Sunfish; Tetraodontiformes: Molidae) are recognizable by their distinct morphological characteristics, including large lobate dorsal and anal fins which fuse to form a clavus in place of a non-existent caudal fin. Adult mola lack axial musculature, but by synchronous flapping of the dorsal and anal fins they are able to dive to depths of 600 meters and cruise at a speed of 3.2 km/h. Larval mola more closely resemble sister species of pufferfish, but early in ontogeny undergo rapid morphological changes. Previous work examined some of the skeletal changes in mola ontogeny using cleared and stained specimens, with particular focus on the formation of the clavus, however, no studies to date have looked at the myological changes that occur as a result of the body shape and skeletal transformations that take place. Using computed microtomography (microCT) scanning, we were able to produce high-resolution three-dimensional skeletons of three stages of mola fry and an adult mola for ontogenetic comparison. Phosphotungstic acid (PTA) staining and re-scanning of mola fry generated images of soft tissue morphology, allowing us to compare muscle volume, position, and fiber angle through ontogeny with measurements from dissections of adult mola. Herein we discuss the functional implications of drastic morphological modeling and changes in body size during ontogeny on the locomotor performance of *Mola mola*.

124-1 BIRCH, S*; PLACHETZKI, D; University of New Hampshire, Durham; *sjb1061@wildcats.unh.edu*
Investigating Sensory Integration and Settlement Responses to Sensory Stimuli in the Hydrozoan Ectopleura crocea
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. However, the sensory modalities that most affect larval settlement decisions are poorly understood in most systems. The benthic marine hydroid *Ectopleura crocea* has an indirect lifecycle that produces a motile larval stage called actinula. While researchers have previously investigated the biology of settlement in actinulae, no study has combined sensory behavior experiments with genomics studies. Here we examine the settlement response of actinula to different light and chemical environments in conjunction with a developmental transcriptome study investigating sensory gene expression. We hypothesize that larval settlement will be most influenced by the combination of biofilm-derived chemical cues and light cues, and that actinula will differentially express taste and chemoreceptors during stages where larvae are competent to settle. We test these hypotheses by combining RNA-seq on various stages of actinula development, from actinula through metamorphosis, with settlement experiments under different sensory conditions. Additionally, we use confocal microscopy at various developmental stages to explore the development of the neural network and its capabilities of sensory integration. Ultimately, our investigations of actinula larva at the molecular level will provide insights into the sensory modalities that influence the settlement decision.

35-2 BIRLENBACH, DM*; KELLER, JS; FOX, DL; University of Minnesota, University of New Mexico; *birle001@umn.edu*
Morphological Similarity in the Dentition of Competing and Non-Competing Rodents
One of the most fundamental species interactions is competition. However, in the fossil record competition cannot be observed or experimentally tested. Instead, paleoecological studies rely on morphological similarity to infer niche overlap. For mammals, similarity in dental morphology is used to argue for overlapping dietary niches and evidence of competition. Here, we test if competitor dentitions are more similar than those of non-competing species. To address this, we collected 535 shape descriptors and ratios of micro-CT scanned lower dentitions of 151 extant rodent species. We compared the differences in the scores of topographic variables used to infer diet, e.g. Dirichlet Normal Energy, Relief Index, and Orientation Patch Count, between 56 competitive species pairs drawn from the literature as well as between species not identified as competitors. We found that competitors are statistically closer in their morphology than non-competitors from the same dietary categories. A subset of the descriptors was then summarized using a principal component analysis. The distance was then determined between each species pair in a principal component morphospace that explained 90% of the variation and on average competitors exhibit significantly closer dental morphology than non-competitors. For 122 species, the morphospace distances were compared to Jaccard Indices (JI) calculated for the overlap in geographic ranges using NatureServe range maps for each species pairing to see if morphological similarity relates to geographic similarity. We found that morphological similarity and JI were poorly correlated suggesting geographic similarity is not well explained by morphological similarity. Our findings support the notion that competitors are more similar morphologically than non-competitors.

36-2 BLACKBURN, DC*; NIELSEN, SV; BAREJ, M; RöDEL, MO; University of Florida, Gainesville, Museum für Naturkunde, Berlin, Museum für Naturkunde, Berlin; *dblackburn@flmnh.ufl.edu*
Systematics and Biogeography of the African Slippery Frogs (genus Conraua), Including the World's Largest Living Frog
The African slippery frogs (genus *Conraua*) contain the largest extant species of frog, *C. goliath*, which can reach 32 cm in length and weigh more than >2.5 kg. The six described species have an unusual disjunct distribution across equatorial Africa, with two species (*C. alleni*, *C. derooi*) in western Africa, three (*C. crassipes*, *C. goliath*, *C. robusta*) in the Lower Guinean Atlantic Forests, and one (*C. beccarii*) in the highlands of Ethiopia and Eritrea. These species typically live in fast moving streams, and four are considered threatened, in part due to human consumption. The biology, evolution, and biogeography of these species remains poorly studied. Using a well-sampled multi-locus dataset, we generate a robust phylogenetic hypothesis for the recognized species that provides insights into the historical biogeography and evolution of body size in this genus. We also find evidence suggesting that populations within the two most widespread species (*C. alleni*, *C. crassipes*) likely represent distinct species requiring description.

15-2 BLUMSTEIN, MB*; RICHARDSON, AR; WESTON, D; ZHANG, J; WELLINGTON, M; HOPKINS, R; Harvard University, Cambridge, Northern Arizona University, Flagstaff, Oak Ridge National Laboratory, Oak Ridge, Oak Ridge National Laboratory, Oak Ridge; *blumstein@fas.harvard.edu*
A new perspective on ecological prediction reveals limits to climate adaptation in a temperate tree species
Forests absorb a large fraction of anthropogenic CO2 emissions, but their ability to continue to act as a sink under climate change depends on plant species undergoing rapid adaptation. Thus, considering the evolution of intraspecific trait variation is necessary for reliable, long-term species projections. We combine ecophysiology and predictive climate modeling with analyses of genomic variation to determine if sugar and starch storage, energy reserves for trees under extreme conditions, can evolve within populations of black cottonwood (*Populus trichocarpa*). Despite current patterns of local adaptation, and extensive range-wide heritable variation in storage, adaptive evolution in response to climate change will be limited by both a lack of heritable variation within northern populations and by a need for extreme genetic changes in southern populations. Our method has implications for species management interventions and highlights the power of using genomic tools in ecological prediction to determine the ability of a species to respond to future climates.

8-6 BO, TB*; TREVELLINE, BK; CABEZAS RUIZ, S; MORRISSEY, C; MARCHANT, TA; ENG, ML; LATTA, SC; KOHL, KD; Univ. of Pittsburgh, Univ. of Saskatchewan, Univ. of Saskatchewan, National Aviary; *botingbei@126.com*

Glucocorticoid Stress Hormones Affect the Gut Microbiota of Captive Birds

Stress exposure affects many aspects of host physiology, and increases in glucocorticoid stress hormones may affect the gut microbiota. Previous studies have shown connections between stress hormones and the gut microbiome, but have only used correlation in the wild or single treatments of stress hormones. Here, we tested whether the gut microbiome responds to the stress hormone corticosterone (CORT) in a dose-dependent manner. Twenty captive European Starlings were randomly divided into four groups (n = 5): Control group (Con, placebo), low-level CORT group (LC, 0.25mg), middle-level CORT group (MC, 1.5mg), high-level CORT group (HC, 7.5mg). Feces were collected before implantation, and 2, 7, 21, 27 days after implantation to understand the temporal changes associated with stress hormones. CORT implantation changed the composition and structure of gut microbiota in birds. We found that birds implanted with the low-level concentration of CORT had increased alpha diversity at the 2 and 7 day (ASV richness and Shannon index). Birds in HC groups exhibited the most distinct microbial communities compared to their starting point, though this effect disappeared within 21 days (unweighted and weighted UniFrac distances). At the phylum level, CORT treatment caused an increase in the abundance of Firmicutes and decrease in Cyanobacteria. These changes were temporary, as the abundances of bacteria partially recovered. Our findings clearly demonstrate a close link between glucocorticoid levels and gut microbiota in captive birds. Furthermore, we demonstrate that the gut microbiome responds to CORT in a dose-dependent manner, and so variation in environmental stress may have variable effects on the gut microbiome in natural populations.

7-2 BOCK, SL*; LOWERS, RH; RAINWATER, TR; HALE, MD; LERI, FM; PARROTT, BB; Univ. of Georgia, Kennedy Space Center, Clemson Univ., Univ. of Virginia; *samantha.bock@uga.edu*

Real-time responses to ecologically-relevant thermal fluctuations during temperature-dependent sex determination in the American alligator

An organism's ability to integrate transient environmental cues experienced during development into molecular and physiological responses forms the basis for adaptive shifts in phenotypic trajectories. During temperature-dependent sex determination (TSD), thermal cues during discrete periods of development coordinate molecular changes that ultimately establish sexual fates and contribute to patterns of inter- and intrasexual variation. How these mechanisms interface with the dynamic thermal environments in nature remains largely unknown. For example, ~70% of American alligator nests exhibit both male- and female-promoting temperatures during the thermosensitive period, often within the span of a daily thermal fluctuation. Here, we investigate how these opposing environmental cues are integrated into sexually dimorphic transcriptional programs across fine temporal scales. Alligator embryos were exposed to fluctuating temperatures based on empirically-derived nest thermal profiles and sampled over the course of a daily thermal fluctuation. Post-transcriptional alternative splicing of epigenetic modifier genes operating upstream in the sex-determining cascade respond rapidly to thermal fluctuations, whereas transcriptional changes of downstream effector genes occur on a delayed timescale. Together our findings reveal how the basic mechanisms of TSD operate in an ecologically relevant context and suggest a hierarchical model in which temperature-sensitive alternative splicing incrementally influences the epigenetic landscape to affect the transcriptional activity of key sex-determining genes.

69-7 BOERSMA, J*; JONES, JA; KARUBIAN, J; SCHWABL, H; Washington State University, Tulane University; *jordan.boersma@gmail.com*

Sex-specific causes and consequences of variable testosterone circulation in a tropical songbird

There is considerable debate about whether testosterone regulates traits similarly in male and female vertebrates. Meta-analyses of the relationship between male and female circulating testosterone have produced conflicting results, highlighting the need for empirical studies in species that exhibit variation in both male and female testosterone and the traits this hormone is known to mediate. The White-shouldered fairywren (Malurus alboscapulatus) demonstrates considerable subspecies-specific variation in testosterone circulation, behavior, and female ornamentation. Testosterone circulation in females appears to be linked to discreet female phenotypes: females from the subspecies with greater ornamentation and aggression circulated higher baseline testosterone, and unornamented females implanted with testosterone produced a major component of ornamental plumage and became more aggressive once the putative signal was acquired. Interestingly, males exhibited opposite patterns in baseline testosterone, as males from the unornamented female subspecies circulated the highest mean testosterone. Our findings challenge the idea that testosterone circulation is correlated and has similar function between sexes. We also present preliminary results from a long-term dataset quantifying variation in testosterone, social networks, and male sexual displays. We address how the social environment influences a suite of functionally linked traits and explore the causes and consequences of variable testosterone circulation between sexes.

13-6 BOGGS, CL; University of South Carolina & Rocky Mountain Biological Lab; *cboggs@seoe.sc.edu*

Trans-generational Ecological Determinants of Egg Composition in the Butterfly Speyeria mormonia

Environmental conditions may affect offspring quality and quantity, which are important fitness components. Here I ask, what are the effects of variable environments on egg composition (offspring quality) in a holometabolous insect species? Using *Speyeria mormonia* (Lepidoptera: Nymphalidae), I focus on triglycerides, which as a group are important energy stores and cryoprotectants for overwintering larvae, which in this species do not feed before entering diapause. Using data from both the field and the lab, I show that triglycerides in eggs increase with the temperature under which the eggs were matured, as well as with larval rearing temperature for the mothers. Neither the larval nor adult food availability to the mother significantly affected the investment of triglycerides in her eggs. However, there was a non-linear trans-generational effect of adult food availability on investment: a female's investment was highest if her own mother experienced intermediate food availability. Any resulting selection pressures will be blunted by the fact that the population as a whole experiences the same conditions, which should lead to smaller effects on relative fitness than on absolute fitness. Nonetheless, which triglycerides are altered, their effects on absolute fitness, and the impacts on the butterfly's life history and population dynamics remain to be explored.

106-4 BOGGS, TE*; FRIEDMAN, JS; GROSS, JB; University of Cincinnati; *boggste@mail.uc.edu*

Parallel adaptation to hypoxia in the blind Mexican cavefish, Astyanax mexicanus.

Hypoxia is an important environmental pressure that likely drives novel adaptive solutions. To cope with this extreme condition, animals often evolve low-oxygen tolerance, or improve oxygen retrieval from their habitat. The blind Mexican cavefish, *Astyanax mexicanus*, inhabits an expansive cave network within the Sierra de El Abra region of northeastern Mexico. The caves in this system are geographically isolated from one another, and demonstrate variably low levels of dissolved oxygen within the subterranean pools. These cavefish, alongside extant 'ancestral' surface morphs, enable powerful comparisons to determine how they thrive under hypoxic conditions. We evaluated hypoxia-tolerance in multiple, independent cave populations at the protein, cellular and genetic levels. We discovered that phylogenetically older populations display higher tolerance to hypoxia compared to phylogenetically younger (and hybrid) populations. These differences include alterations in hemoglobin concentration, as well as higher expression of a cohort of hemoglobin genes. This work provides insight to the genetic changes mediated hypoxia tolerance in blind cavefish, and showcases the diverse genetic and cellular strategies of adaptation among independent cavefish populations of the Sierra de El Abra.

29-5 BOLMIN, O*; ALLEYNE, M; WISSA, AA; University of Illinois at Urbana-Champaign; *obolmin2@illinois.edu*

How does Morphology Affect Jumping Kinematics of Click Beetles?

When unconstrained and from an inverted position, click beetles (Coleoptera:Elateridae) fold their body extremely rapidly to propel themselves into the air. This unique legless jumping mechanism is enabled by a thoracic hinge and is power amplified. The jump is divided into three stages: the pre-jump (energy storage), the take-off and the airborne stage (energy release). In this presentation, we answer the following questions: what are the dominant kinematic and the external morphological parameters driving the jump, how are they correlated and what is their respective contribution to the jump performance? The morphological measurements of 88 specimens from 13 genera, namely *Aeolus mellilus, Agriotes sp., Alaus myops, Alaus oculatus, Athous sp., Ampedus linteus, Ampedus nigricollis, Hemicrepidius sp., Lacon Marmoratus, Limonius sp., Melanactes sp., Melanotus sp., Parallelosthetus attenuatus*, of various sizes and shapes (body length varying from 2 to 35 mm) were taken. The take-off and airborne stages of the jumps of 54 specimens from 11 of these genera were recorded using high-speed video imaging. All videos were post-processed using ProAnalyst and Matlab software to derive kinematic jumping parameters of each specimen. From the morphological measurements, we show isometric scaling across species. Kinematic parameters such as the take-off velocity, acceleration and angle as well as morphological measurements such as the body length, mass, and elytra curvature for each specimen are used to compare the jump performance within and across species.

57-7 BONIER, F*; COX, RM; Queen's University, University of Virginia; *bonierf@queensu.ca*

To each their own? Meta-analysis of evidence of optimality of endocrine phenotypes

Rosemary Knapp's research contributions emphasize the importance of considering individual life history stage and strategy when seeking to understand endocrine traits. This perspective has been central in clarifying the role of endocrine signals in regulating complex life history traits, and for understanding variation among individuals in responses to the same signals. In essence, this work placed the endocrine phenotype into an ecological and evolutionary context, and recognized that optimal endocrine phenotypes differ not only among the sexes, but also within sexes, among individuals with alternative reproductive tactics. Here, we extend this view to consider variation among individuals, rather than among morphs. If individuals express near-optimal endocrine phenotypes, well matched to their context, we predict that manipulations of these phenotypes (e.g., through hormone implants) should generally compromise fitness. We use a meta-analysis of hormone manipulation studies to test this prediction, and find some support for it, along with interesting sources of variation. Effects of hormone manipulations on fitness varied depending on the sex of individuals being manipulated, as well as on the metric used to estimate fitness. These findings reinforce the importance of understanding individual life history and environmental context when we seek to understand how selection has shaped, and is shaping, endocrine traits.

43-2 BONTRAGER, M; MUIR, CD*; MAHONY, C; GAMBLE, DE; GERMAIN, RM; HARGREAVES, AL; KLEYNHANS, EJ; THOMPSON, KA; ANGERT, AL; University of British Columbia and University of California, Davis, University of Hawai'i, University of British Columbia, University of British Columbia, McGill University; *cdmuir@hawaii.edu*

Climate anomalies are altering local adaptation

Adaptation to local climate is ubiquitous, but global climate change may be generating mismatch between the conditions that populations experience and the optima to which they have evolved. This mismatch is likely to decrease individual fitness and disrupt local adaptation. We investigate these effects with a synthesis of data from 149 published transplant studies, and find that fitness declines when populations experience temperatures that deviate from their historic averages, but is not sensitive to precipitation variation. Deviations in temperature affect the magnitude of local adaptation detected in transplant experiments. The negative effects of climate anomalies on fitness and local adaptation may be an early warning sign that populations are at risk in the absence of rapid adaptation or gene flow

S6-2 BOONMAN, ARJAN*; EITAN, OFRI; YOVEL , YOSSI; University of Tel Aviv; *arjan.boonman@gmx.net*
The acoustics of flapping flight in birds and bats; a preliminary analysis
Most studies on the acoustics of bird flight focus on gliding- and not on flapping flight. Here we present preliminary acoustic data on the sound of wing-flapping in a number of bat- and bird species. We did not record the acoustics of the wing-beat rate itself but of the acoustic impulses created by each individual flap of the wing. In this context we show that during take-off, when barn owls must flap strongly to create sufficient lift, the sounds of wing-flaps are clearly audible. We also present a case of specialized 'wing-claps' used by fruit bats in the Old World. The exact mechanism of creating each clap is still unknown, but we proved these claps to be used in a form of rudimentary echolocation to detect large structures.

38-4 BORTONI, A*; MORRIS, AT; YOUNG, IR; BREUER, KS; SWARTZ, SM; Brown University, Providence, USA; *alberto_bortoni@brown.edu*
Synchronous Muscle Recruitment for Stable Flight Control in Egyptian Fruit Bats
Bats demonstrate a remarkable capacity to recover flight stability after perturbations from the environment. This ability is likely supported by the precisely-timed recruitment of wing muscles, which modulate the production of aerodynamic forces. However, we know little about neuromuscular control mechanisms in bat flight. Studies of limb movement in response to perturbations during terrestrial locomotion show a proximo-distal control gradient in which performance of muscles that control proximal joints is insensitive to perturbations, in contrast to activity of muscles controlling more distal joints. We hypothesized that when flight is asymmetrically perturbed, the activity of left and right pectoralis major muscles would remain synchronized. To test this, we recorded electrical activity of the pectoralis muscles using wireless dataloggers (Vesper Pipistrelle, 4.1g) from five *Rousettus aegyptiacus* trained to fly along a corridor (1.5 x 6.0 x 2.0m). Bats passed through a window that divided the corridor's length in half en route to a landing pad; in perturbed flights, a jet of air was delivered to one wing (2.5X body weight) as bats flew through the window. We tracked the 3D position of 15 markers on each individual using six high-speed cameras. We compared the timing of muscle recruitment with kinematics for all flights. Results show symmetrical recruitment in all flight trials, demonstrating that recovery of stable flight after perturbation does not alter the recruitment symmetry of the pectoralis in *Rousettus aegyptiacus*. This supports the idea that proximo-distal limb muscle activation gradients are a fundamental characteristic of vertebrate neuromechanical control.

68-6 BOVE, CB*; DAVIES, SW; RIES, JB; UMBANHOWAR, J; MCCOPPIN, J; FARQUHAR, E; CASTILLO, KD; UNC-Chapel Hill, Chapel Hill, NC, UNC-Chapel Hill, Chapel Hill, NC and Boston University, Boston, MA, Northeastern University, Boston, MA; *colleenbove@gmail.com*
Physiological and transcriptomic responses of coral hosts and algal symbionts of four Caribbean corals under global change
The continued rise in ocean pCO_2 and temperature is of concern for marine organisms, especially highly susceptible reef-building corals that rely on a relationship with symbiotic algae, which governs the success of the coral holobiont. Diverse physiological responses of coral holobionts, at individual and species levels, will determine the future success of coral reefs. We investigated the independent and combined effects of acidification (2803300 µatm) and warming (28, 31 °C) on the physiological responses of coral hosts and algal symbionts of 4 Caribbean coral species (*Siderastrea siderea, Pseudodiploria strigosa, Porites astreoides, Undaria tenuifolia*) from inshore and offshore reefs on the Belize Mesoamerican Barrier Reef System. To illuminate molecular underpinnings of these responses, gene expression of *S. siderea* were explored. Warming more negatively altered host physiology of *S. siderea*, while symbiont physiology responded to warming and acidification. Preliminary gene expression showed transcriptome resilience across stressors, however, natal reef drove gene expression profiles. Warming reduced *P. strigosa* host and symbiont physiology, although inshore symbionts were less affected. Host physiology and chlorophyll a of *P. astreoides* were reduced under acidification, while chlorophyll a increased with warming. Determination of *U. tenuifolia* physiology was difficult due to high mortality. These results highlight diverse physiological responses of coral holobionts under global change and understanding this variation is critical to predicting the future of Caribbean reefs as global change continues.

74-8 BOVO, RP*; SIMON, MN; PROVETE, DB; NAVAS, CA; ANDRADE, DV; University of Sao Paulo and University of California Santa Cruz, University of Sao Paulo, Federal University of Mato Grosso do Sul, Sao Paulo State University; *rpbovo@gmail.com*
Intraspecific Variation in Thermal Tolerance and Water Balance of Amphibians Across Subtropical Elevational Gradients
Most empirical studies have used interspecific comparisons to assess vulnerability to environmental/climate change. However, intraspecific variation is the source of evolution and population or species differences in variation can result in different responses to such changes. In this study, we test how altitudinal gradients affect variation of thermal and hydric traits - both strongly associated with the evolutionary history - in amphibians. We compared mean thermal and hydric traits across different altitudes within-species in five anuran species. We sampled specimens from two mountain ranges at the Brazil's Atlantic Rainforest, from sea level to 1600 m, and measured thermal tolerance (critical thermal maximum, CTmax, and minimum, CTmin) and water balance (rates of evaporative water loss, EWL, and water uptake, WU). We hypothesized that populations from highlands would show lower CTmin, CTmax, EWL and higher WU, as well as higher thermal tolerance range (i.e., thermal fundamental niche, TFN) and warming tolerance (WT, i.e. the difference between CTMax and the maximum temperature of the environment). Effect of altitude was stronger in thermal traits compared to hydric ones. For most species, we confirmed our expectations for CTmin, CTmax, WT and TFN, however EWL or WU showed no difference along the elevational gradient. Taken together, our results indicate that species respond in different degrees to environmental/climate change and, therefore, assessment of vulnerability can be biased depending on which population is measured. This has implications on predictability of climate change impact on species, and deserves further consideration.

38-5 BOYNTON, AM*; CARRIER, DR; University of Utah; *alicia.boynton@utah.edu*

Function of cervical muscles during human running

Core musculature functions to stabilize the pelvis and trunk against moments imposed by activity of extrinsic limb muscles. Conventionally, the human core is thought to include the axial muscles located between the pelvis and the diaphragm. We suspect, however, that the core includes all of the axial muscles of the trunk and neck. During running, the muscles of the human neck must function to control the posture of the head, but they may also play a role in stabilizing the trunk against the moments imposed on the pelvis by the extrinsic leg muscles. To test if neck muscles play a role in controlling the posture of the head we monitored changes in their activity when subjects ran with 4.5 kg added to their heads, roughly doubling head mass. If activity of neck muscles is required to control head posture, we would expect muscle activity to increase substantially when head mass is doubled. To test whether cervical muscles play a role in core stabilization we increased the fore-aft and vertical forces of running with elastic tethers attached to the subjects via a waist harness. If neck muscles do play a role in core stability, we predict that higher locomotor forces will be associated with elevated cervical muscle activity. We found that when subjects ran at constant speed (2.7 m/s) doubling the mass of the head had little or no effect on the activity of the muscles we monitored. In contrast, alterations of forces imposed on runners in the fore-aft direction resulted in significant changes in cervical muscle activity. These results suggest that superficial cervical muscles act as part of the human core to stabilize the trunk against moments imposed at the pelvis by extrinsic leg muscles during running. The observation that neck muscles provide stability for the legs of humans has implications to the locomotor function of the tetrapod neck, prevention of spinal injury, and treatment of chronic cervical and back pain.

129-7 BRACKEN-GRISSOM, H.D*; DELEO, D.M; PORTER, M.L; IWANICKI, T.; SICKLES, J.; FRANK, T.M; Florida International University , University of Hawai'i at Mānoa, University of Hawai'i at Mānoa, Nova Southeastern University; *hbracken@fiu.edu*

Evidence for Extraocular Photosensitivity in the Bioluminescent Organs of Deep-sea Shrimp

Extraocular photoreception has not been previously described in deep-sea invertebrates. Here, we investigate photosensitivity in the bioluminescent light organs (photophores) of deep-sea shrimp, an autogenic system in which the organism possesses the substrates and enzymes to produce light. Through the integration of transcriptomics, in situ hybridization and immunohistochemistry we find evidence for the expression of opsins and phototransduction genes known to play a role in light detection in most animals. Subsequent shipboard light exposure experiments showed ultrastructural changes in photophores similar to those seen in crustacean eyes providing further evidence that these photophores are photosensitive. In many deep-sea species, it has long been documented that photophores emit light to aid in counterillumination – a dynamic form of camouflage that requires adjusting the organ's light intensity to "hide" their silhouettes from predators below. However, it remains a mystery as to how animals fine-tune their photophore luminescence to match the intensity of downwelling light. Photophore photosensitivity allows us to reconsider the organ's role in counterillumination - not only in light emission but also light detection and regulation.

70-7 BRADY, PC*; GARCIA, M; HERNANDEZ, T; AALUND, M; GRUEV, V; CUMMINGS, ME; University of Texas at Austin, University of Illinois at Urbana Champaign; *scorpionjeger@hotmail.com*

Measurement of cephalopod polarization patterns with color video-polarimetry and computer vision techniques.

Cephalopods have long been known to visually sense polarized light, yet quantifying polarized patterns from these animals has been lacking due to technical difficulties of polarization imaging underwater. We use a custom-built high definition color polarization camera with vertically stacked color photodetectors that has been engineered to be diver operated under water. We use a modified the computer vision tool, perspective from n points (PnP), to fit a virtual 3D model to the 2D image. Using this 3D model, we model the polarization reflections in virtual space and compare with the measured animal. Reef squid, Sepioteuthis lessoniana and Sepioteuthis sepioidea, show specific patterns of the degree of polarization that are dependent on the solar and viewing angle. Specific angle of polarization patterns were found that are not correlated with the solar position. These polarization patterns may contribute to the unique and intricate schooling patterns found in these squid. We quantify these schooling patterns using a goPro-VLAM tracking technique that is able to measure the body positions of animals in addition to being able to map their environment. The Broadclub Cuttlefish, Sepia latimanus show rapid changes in polarization states in response to the movement of the videographer.

63-7 BRASS, KE*; HERNDON, N; GARDNER, S; GRINDSTAFF, J; CAMPBELL, P; Oklahoma State University, University of California, Riverside, and Oklahoma State University, University of California, Riverside, and Oklahoma State University; *kbrass@okstate.edu*

Epigenetic effects of paternal perception of predation risk on offspring phenotypes

In stable environments, parents able to transmit information such as predation risk should have offspring that are pre-adapted to the environment they will encounter as adults. While intergenerational epigenetic transmission of paternal experience has been demonstrated in mammals, whether paternal perception of predation risk can alter offspring phenotypes has not been investigated. We exposed male mice to a predator odor (2-4-5-trimethylthiazoline, TMT) and measured offspring behavioral phenotypes throughout development as well as adult neural gene expression and stress reactivity. We predicted that offspring of males exposed to TMT would exhibit decreased activity and increased anxiety-like behaviors relative to controls because these behaviors are analogous to anti-predator behaviors in the wild. Unexpectedly, we found that offspring of TMT-exposed males tend to be more active and exhibit fewer anxiety-like behaviors relative to controls. In the prefrontal cortex, we found evidence of increased relative expression of the mineralocorticoid receptor (Nr3c2) in experimental offspring. Additionally, offspring of TMT-exposed males exhibited decreased baseline plasma CORT relative to controls. These results suggest that fathers exposed to predation threat produce offspring that are bolder and, potentially, more likely to flee than freeze when predators are present. Importantly, this study provides evidence that ecologically relevant paternal experience can influence offspring phenotypes.

74-6 BREITENBACH, AT*; PAITZ, RT; BOWDEN, RM; Illinois State University, Normal; *atbreit@ilstu.edu*

Let's Do the Time-lag Again: Ecologically Relevant Incubation Temperatures Delay the Response of Sex-determining Genes in a Turtle with TSD

Even though most organisms are exposed to variable bouts of warm temperatures, we know relatively little about how the timing and continuity of heat exposure influences biological processes. If heat waves increase in frequency and duration as predicted by climate change models, it is important to understand how these bouts of warmer temperatures could affect thermally sensitive species, including reptiles with temperature-dependent sex determination. We hypothesized that 1) the continuity of exposure to warm temperatures would affect resulting sex ratios in *Trachemys scripta* hatchlings, and 2) the duration of exposure to warm temperatures would affect the expression of two genes in the sex-determination cascade, *aromatase* and *Dmrt1*. To test the first hypothesis, eggs were initially exposed to daily fluctuations of 25±3°C (which produce all males) and then two 7-day heat wave days of 29.5±3°C separated by varying amounts of days at 25±3°C (sex ratio data to be collected October 2019). To test the second hypothesis, we exposed eggs to a 9-day heat wave (same thermal parameters), and sampled embryonic gonads on the last day of the heat wave as well on days 1, 3, 5, and 7 after the end of the heat wave. Surprisingly, neither *Dmrt1* nor *aromatase* increased in expression following the heat wave. Expression of both genes slightly decreased after the last heat wave day, and then gradually increased back to initial levels. These data suggest that the response of some sex-determining genes to fluctuating temperatures may be slower than has been defined by constant temperature studies and underscore the importance of accounting for natural variation in temperature when studying such phenomena in the laboratory.

113-2 BRESSMAN, NR*; HILL, JE; ASHLEY-ROSS, MA; Wake Forest University, Winston Salem, NC, Tropical Aquaculture Laboratory, University of Florida, Ruskin, FL; *noahbressman@gmail.com*

Why (and how) did the catfish cross the road? Chemoreceptive terrestrial orientation and amphibious natural history of the invasive walking catfish (Clarias batrachus)

Walking catfish (*Clarias batrachus*) are an invasive species in Florida, renowned for their air-breathing and terrestrial locomotor capabilities. However, it is unknown how they orient in a terrestrial environment. Furthermore, while anecdotal life history information is widespread for this species in its nonnative range, little of this information exists in the literature. The goals of this study were to identify sensory modalities that walking catfish use to orient on land, and to describe the natural history of this species in its nonnative range. Fish (n = 100) were collected from around Ruskin, FL, and housed in a greenhouse, where experiments took place. Individual catfish were placed in the center of a terrestrial arena and were exposed to four treatments: deionized water- and alanine solution-wetted bench liner in direct contact with the fish, and pools of filtered and pond water out of direct view or contact. Additionally, 88 people from Florida wildlife-related Facebook groups who have personal observations of walking catfish on land were interviewed for information regarding their terrestrial natural history. This data was combined with observations from 38 YouTube videos of walking catfish in Florida. Walking catfish exhibited significantly positive chemotaxis toward alanine, suggesting chemoreception is important to their terrestrial orientation. Walking catfish emerge most frequently during or just after heavy summer rains, particularly from storm drains in urban areas, where they may feed on terrestrial invertebrates. By better understanding the full life history of walking catfish, we can improve management of this invasive species.

S3-4 BRINK, KS*; CHUONG, CM; WU, P; RICHMAN, J; University of British Columbia, University of Southern California; *kirstin.brink@gmail.com*

Effects of Premature Tooth Extraction on Tooth Replacement Rates in Iguana iguana

Reptiles with continuous tooth replacement, or polyphyodonty, replace their teeth in predictable, well-timed waves in alternating tooth positions around the mouth. This process is thought to occur irrespective of tooth wear or breakage. However, premature extraction of functional teeth in alligators stimulates dental epithelial cell proliferation, potentially leading to faster tooth replacement. Therefore, without a long-term study, it is unknown if these early changes in cell proliferation lead to more rapid tooth replacement or if timing is in fact intrinsically controlled. Furthermore, it is unknown if this proliferation is unique to crocodilians or is characteristic of all reptiles. In this study, we aimed to determine if tooth extraction affects tooth replacement timing long-term in juvenile green iguanas. We analysed an historical collection of x-rays collected for up to 7 months after functional tooth extraction. We also performed new extraction experiments for molecular characterization of dental tissues. Results show that premature tooth extraction has no effect on tooth replacement timing, and teeth are replaced on average every 20 weeks at each position. Cell proliferation is not detected until 12 weeks after extraction in the successional lamina, matching the expected development time of a tooth in iguanas. The differences observed in molecular activity in the successional lamina between alligators and iguanas could be due to the morphology of the dental lamina and maintenance of potential stem cells, tooth attachment type, or feeding ecology. Ongoing longitudinal studies in the alligator and leopard gecko will further elucidate the mechanisms of continuous tooth replacement in polyphyodont reptiles.

17-3 BRISCOE, AD*; MACIAS-MUñOZ , A; RANGEL-OLGUIN, AG; BRISCOE, Adr; University of California, Irvine; *abriscoe@uci.edu*

Evolution of Phototransduction Genes in Lepidoptera

Vision is underpinned by phototransduction, a signaling cascade that converts light energy into an electrical signal. Among insects, phototransduction is best understood in *Drosophila melanogaster*. Comparison of *D. melanogaster* against three insect species found several phototransduction gene gains and losses, however, lepidopterans were not examined. Diurnal butterflies and nocturnal moths occupy different light environments and have distinct eye morphologies, which might impact the expression of their phototransduction genes. Here we investigated: 1) how phototransduction genes vary in gene gain or loss between *D. melanogaster* and Lepidoptera, and 2) variations in phototransduction genes between moths and butterflies. To test our prediction of phototransduction differences due to distinct visual ecologies, we used insect reference genomes, phylogenetics, and moth and butterfly head RNA-Seq and transcriptome data. As expected, most phototransduction genes were conserved between *D. melanogaster* and Lepidoptera, with some exceptions. Notably, we found two lepidopteran opsins lacking a *D. melanogaster* ortholog. Using antibodies, we found that one of these opsins, a candidate retinochrome, which we refer to as unclassified opsin (UnRh), is expressed in the crystalline cone cells and the pigment cells of the butterfly, *Heliconius melpomene*. Our results also show that butterflies express similar amounts of *trp* and *trpl* channel mRNAs, whereas moths express 50X less *trp*, a potential adaptation to darkness. Our findings suggest that while many single-copy *D. melanogaster* phototransduction genes are conserved in lepidopterans, phototransduction gene expression differences exist between moths and butterflies that may be linked to their visual light environment.

3-1 BROWN, CE*; DEBAN, SM; DUDLEY, R; SATHE, EA; University of South Florida, Tampa, FL, University of California, Berkeley, CA, University of California, Berkeley, CA; *cbrown43@mail.usf.edu*

Directed Aerial Descent in Arboreal Salamanders

Many arboreal animals, from insects to vertebrates, use directed aerial descent (DAD) to avoid predation, locate mates or resources, and minimize deleterious impacts of a jump or fall. Such behaviors may have been an important precursor to the evolution of flight in vertebrates, and thus merits closer inspection even outside the context of the arboreal-cursorial debate. Here, we show that arboreal salamanders in the genus *Aneides*, some of which inhabit the crowns of the world's tallest trees, use DAD during jumps despite having no apparent specialized aerodynamic control surfaces such as skin flaps. High-speed cameras were used (at 500 fps) to image arboreal salamanders from dorsal and lateral perspectives as they jumped from both raised platforms onto a landing pad, and into a vertical wind tunnel that simulated an extended descent. One non-arboreal plethodontid, *Ensatina eschscholtzii*, was studied in the vertical wind tunnel for direct comparison. *E. eschscholtzii* cannot jump, and its aerial performance varies greatly. Kinematic analysis revealed that all filmed salamanders were capable of mid-air stabilization, parachuting, and landing in a prone posture during jumps or falls. *Aneides vagrans* may also be capable of controlled maneuvers during extended descents as simulated in the vertical wind tunnel. Mid-air stabilization, parachuting, and maneuvers appear to be controlled by deliberate movements of the limbs, feet, and tail of these arboreal salamanders. This new example of DAD, the first to document the mechanics of aerial behavior in any salamander, suggests that the oft-cited long limbs and active tail of *Aneides* may serve in functions supplemental to climbing, and also is relevant to aerial hypotheses for the origin of flight in vertebrates.

117-2 BROWN, T A*; TSURUSAKI, N; BURNS, M; UMBC, Baltimore, MD, Tottori University, Tottori, JPN; *tbrown8@umbc.edu*

Genotyping-By-Sequencing via 3RAD Capture to Determine Reproductive Mode in a Facultative Parthenogen

Alternative reproductive systems, wherein individuals do not exclusively reproduce sexually, may provide unique insight regarding sexual conflict. *Leiobunum manubriatum* and *L. globosum* are facultatively parthenogenetic Japanese harvestman which vary in sex ratio across their geographic distribution. Males of both species possess morphology which suggest coercion may be common during mating events. In previous efforts, we used genotyping-by-sequencing and a SNP array panel to determine the reproductive mode of females. We found that despite the availability of males, females in populations with high male frequency reproduced primarily through parthenogenesis. Additionally, females from populations with few males were not significantly more fecund than females in equal sex ratio populations. These results also identified that a more accurate, cost-effective method to rapidly genotype thousands of samples was necessary. 3RAD Capture combines the low input DNA requirements and decreased PCR error rate of 3-enzyme RADseq with the high coverage of bait capture sequencing. First, specialized capture baits were designed from previous RAD sequencing of *L. manubriatum*. These baits target loci suitable for genotyping, maximizing usable reads from minimal template DNA. Samples were digested using three enzymes, and custom oligonucleotides were ligated to cut ends. Following this preparation, the library is hybridized with bait probes which are targeted with streptavidin beads. The captured DNA can then be isolated and sequenced with high efficacy. Rapid and accurate genotyping facilitates sire assignment of thousands of egg specimens, providing insight on the factors which maintain sex in these facultative parthenogens.

140-3 BRUECKNER, A*; PARKER, J; California Institute of Technology, Pasadena, CA; *bruckner@caltech.edu*

Single Cell Assembly of a Chemical Key Innovation in a Rove Beetle

Evolutionary novelty can arise from the emergence of new cell types with new biological functions. How new cell types are constructed molecularly during evolution is poorly understood. Here, we deconstruct the assembly of novel cell types comprising an evolutionary key innovation in animals using single cell sequencing. A chemical defense gland in rove beetles (Staphylinidae) is the putative catalyst behind the global radiation of this clade into >16,000 species. We show how defense gland function was pieced together from ancestral molecular source material to create two, clade-specific secretory cell types, each capable of synthesizing and secreting distinct compound classes. Production of noxious benzoquinones by one cell type evolved from duplication of a tyrosine-oxidizing laccase enzyme, with an ancestral role in cuticle tanning. Production of a short-chain alkane by the second cell type evolved from recruitment of a partially duplicated cuticular hydrocarbon pathway lacking elongase-mediated chain extension. The alkane-producing cells form an epithelial reservoir into which both cell types secrete, the alkane dissolving the benzoquinones to create a bioactive defensive secretion. These results exemplify how cell types with new properties are constructed through molecular evolution, and can synergize to create emergent organ functions.

126-6 BUCHINGER, TJ*; FISSETTE, SD; BRANT, CO; LI, K; JOHNSON, NS; LI, W; Michigan State University, East Lansing, MI, US Geological Survey's Hammond Bay Biological Station, Millersburg, MI; *buching6@msu.edu*

A Pheromone Antagonist Liberates Female Sea Lamprey From a Sensory Trap

The sensory trap hypothesis predicts males use signals that mimic nonsexual cues to gain access to mates. In theory, deceptive signaling might lead to honest communication if females evolve to discriminate the mimic from the model and react appropriately to each per the context. We investigated if and how female sea lamprey (*Petromyzon marinus*) discern a nonsexual chemical cue from a male pheromone that mimics it. Sea lamprey migrate into streams following chemical cues released by larvae residing in nursery habitats near spawning grounds. Sexually mature males signal to females using a sex pheromone that partially mimics the larval cue; the major component of the male pheromone 3-keto petromyzonol sulfate (3kPZS) is also released by larvae and influences the nonsexual migratory behavior of sea lamprey and other species that do not use it as a sex pheromone. We postulated females discriminate between the larval cue and the male pheromone using petromyzonol sulfate (PZS), a behavioral antagonist of 3kPZS. Chemical analysis confirmed that both larvae and males release 3kPZS but revealed proportionally more PZS in larval odor than male odor. In a natural stream, 100% of females chose the nest baited with a mixture of 3kPZS and PZS typical of males over that of larvae when each was applied at the same concentration of 3kPZS. Our results indicate females use a behavioral antagonist to avoid orienting towards larval odor while tracking the male pheromone that mimics it, and offer rare evidence females can adapt to use mimetic male signals for honest communication.

41-7 BUCKLEY, KM; Auburn University; *kbuckley@auburn.edu*
Immune Responses in Sea Urchin Larvae Highlight Fundamental Aspects of Animal Immunity
Wide-ranging aspects of organismal biology are influenced by the microbial world. By orchestrating these relationships – through protecting against pathogens and promoting a beneficial microbiota – the immune system operates at the forefront of evolutionary biology. Immune response is a system-wide phenomenon that integrates mechanisms for microbial detection and clearance with physiological pathways that maintain host homeostasis. The larval stage of the purple sea urchin (*Strongylocentrotus purpuratus*) provides an experimentally tractable, morphologically simple system in which to study immunity from a system-wide perspective. In response to marine bacterium *Vibrio diazotrophicus* in the seawater, larvae elicit a synchronous, non-lethal inflammatory response. The cellular response consists of changes in gut morphology, immune cell recruitment, and changes in cell motility. Analysis of gene activity reveals that the most acutely upregulated gene in the early phase of response are two groups of IL17 paralogs, which are expressed exclusively in gut epithelial cells. Perturbation of IL17 receptor signaling results in reduced levels of tnfaip3 (an IL17 feedback inhibitor), nfkbiz (an IL17 target gene in vertebrates), transcription factors cebp and cebp and soul1 (SOUL domains are evolutionarily widespread and involved in immune responses). These results indicate that the highly regulated IL17 expression in the gut epithelium and signaling through IL17R1 form a central axis of larval gut-associated immunity. Transcriptional regulation is also apparent within a battery of genes with homologs throughout non-vertebrate bilaterian organisms. As invertebrate deuterostomes, sea urchin larvae share an important genetic heritage with the vertebrates but provide an experimentally tractable system. These findings define fundamental aspects of immune control and are relevant for understanding gut immunity in a wide range of animals.

93-6 BUO, C*; TAYLOR, E; BARTLES, J; CHRISTMAN, K; DAYAL, P; LONDRAVILLE, RL; University of Akron; *cb46@zips.uakron.edu*
Spatial mapping and visual cues influence navigation in Entomacrodus striatus
We collected *Entomacrodus striatus*, an amphibious rockskipper, from a rock jetty in Moorea, French Polynesia, and tested their jumping abilities using a flow table. Amphibious fish routinely navigate between terrestrial and aquatic habitats using either spatial mapping or visual cues to determine where to safely jump. We recorded jumping direction during three sets of trials: eleven rounds of training, three rounds of visual cue disruption testing, and two rounds of spatial memory disruption testing. During the first round of training, the fish were able to jump to safety in a novel environment, regardless of starting orientation ($p < 0.001$). *E. striatus* were able to learn the terrain after repeated conditioning and continued to jump in the same direction after we moved rocks to the opposite side of the table ($p = 0.033$). To test memory disruption, we injected the fish with NOS inhibitor L-NAME and found fish jumps became randomly distributed ($p = 0.452$). In this study, we show blackspotted rockskippers successfully navigate through a combination of both visual cues and spatial mapping while on land.

2-7 BURFORD, B*; WILD, L; SCHWARZ, R; KOSMA, M; CHENOWETH, E; SREENIVASAN, A; GILLY, W; HEINTZ, R; FIELD, J; HOVING, HJ; STRALEY, J; DENNY, M; Stanford University, University of Alaska Fairbanks, GEOMAR, University of Alaska Southeast, Alaska Fisheries Science Center, Southwest Fisheries Science Center, GEOMAR; *bburford@stanford.edu*
Poleward proliferation of an inshore squid
Ongoing shifts in temperature and oxygen availability are thought to alter the abundance and distribution of metabolically-viable habitats for marine ectotherms. Motile species with larger bodies and longer lifespans can compensate by migrating long distances to inhabit more suitable waters. These "climate refugees" then interact with and potentially affect their new ecosystems. However, smaller-bodied species with short lifespans are thought to remain within ecosystems, where they exhibit recurrent boom-bust dynamics. California market squid (*Doryteuthis opalescens*) is a small, abundant, and ecologically-important marine ectotherm that primarily inhabits the California Current (CC) in the northeast Pacific Ocean. With a typical lifespan of 6 months, population fluctuations in the CC that correlate with changes in oceanographic conditions have largely been attributed to boom-bust dynamics, and little attention has been given to the species' latitudinal migratory potential. However, beginning in 2015, *D. opalescens* appeared in unprecedented abundance in the Gulf of Alaska (GOA), an ecosystem 3,000 km northwest of the central CC. We relate this multi-generational poleward migration to ecophysiology, life history, and trophic ecology, and examine the event's historical, geographic, and environmental context. Our data suggest that the causes and consequences of climate-related migrations in small, short-lived marine ectotherms have important implications both for the life history of the migrants and the ecology of the communities and ecosystems into which they migrate.

71-3 BURKHARD, TT*; PHELPS, SM; University of Texas at Austin; *tburk@utexas.edu*
Evidence for heritable variation in the songs of Alston's singing mouse
Advertisement vocalizations can attract mates, deter rivals, aid in species recognition, and drive reproductive isolation. Because adaptation relies on heritable variation, examining the heritability (h^2) of acoustic variation is critical to understanding the evolution of vocalizations and the species that make them. Alston's singing mouse (*Scotinomys teguina*) is a small and diurnal species that lives in cloud forests of Central America. We used a combination of breeding studies and genomics-based methods to test for heritable variation in song structure among these mice both in the lab and field. We first took advantage of geographic variation in song effort to experimentally examine whether heritable variation contributes to intraspecific differences in song. We caught animals from Costa Rica and Panama, populations that naturally differ in song length. We reared animals from each of these sites in captivity, and crossed them to produce F_1 and F_2 animals, recording songs from each of these three generations. Population differences in song elaboration were maintained in lab-reared animals, suggesting a heritable basis to population differences, with F_1 and F_2 animals exhibiting intermediate song lengths. Next, we estimated the heritability of song within a Costa Rican population. We recorded songs and collected DNA from wild-caught mice. We used RAD-seq to generate SNPs from each individual and to calculate a genomewide relatedness matrix (GRM). Finally, we fit generalized linear mixed models to calculate h^2 of song. Our preliminary results estimate h^2 to be between 0.2 - 0.4 for different aspects of song. Together our data support the hypothesis that there is heritable variation in song structure both within and among populations of singing mice.

S11-10 BURMEISTER, SS*; LIU, Y; University of North Carolina, University of Texas Southwestern Medical Center; *sburmeister@unc.edu*

Hippocampal transcriptomes are associated with cognitive ability in two species of frog

The complexity of an animal's interaction with its physical and/or social environment is associated with behavioral flexibility and cognitive complexity. While this relationship has been studied extensively in birds and mammals, we know comparatively little about cognitive ecology in amphibians. We examined differences in cognitive ability in two species of frog with divergent natural histories. Poison frogs are diurnal, territorial, and utilize spatially distributed resources during parental care. Túngara frogs are nocturnal and use ephemeral puddles to breed in a lek-type mating system. Using standardized laboratory tasks, we find that green-and-black poison frogs (*Dendrobates auratus*) prefer to use spatial cues while túngara frogs (*Physalaemus pustulosus*) prefer local cues. Further, green-and-black poison frogs display greater behavioral flexibility than túngara frogs in a reversal learning task. Finally, green-and-black poison frogs are capable of using true spatial memory to solve a modified Morris water maze. Spatial memory and behavioral flexibility are associated with hippocampal function in mammals. Thus, we used RNAseq to examine species differences in the medial pallium, the amphibian homolog of the hippocampus. We found that genes related to learning and memory, neurogenesis, and synaptic plasticity were upregulated in green-and-black poison frogs, while genes related to apoptosis were upregulated in túngara frogs. While there are many reasons that these two species may differ in medial pallium gene expression, such differences provide an opportunity to identify candidate genes that enable greater behavioral flexibility and cognitive complexity in green-and-black in poison frogs.

S11-1 BURMEISTER, SS; University of North Carolina; *sburmeister@unc.edu*

Integrative Comparative Cognition

A long-standing question in biology is *what are the mechanisms that shape the evolution of cognition?* One effective way to address this question is to study cognitive abilities in a broad spectrum of animals. While comparative psychologists have traditionally focused on a narrow range of organisms, today they may work with lizards, birds, or bees. This broader range of study species has greatly enriched our understanding of the diversity of cognitive processes among animals. Yet, this diversity has highlighted the fundamental challenge of comparing cognitive processes across animals. An analysis of the neural and molecular mechanisms of cognition may be necessary to solve this problem. For example, if similar cognitive abilities are mediated by different neurobiological mechanisms, this may support the conclusion that they are not, after all, comparable. Further, a mechanistic approach can inform how the evolution of cognitive abilities have been constrained at the neural, molecular, or genetic levels. Recent advances in next-generation sequencing enables one to study neurogenomic mechanisms of comparative cognition in a broader range of species providing a potentially powerful tool to create an integrative perspective of comparative cognition.

S7-1 BURNETT, KG*; DURICA, DS; MYKLES, DL; STILLMAN, JH; College of Charleston, The University of Oklahoma, Colorado State University, San Francisco State University; *burnettk@cofc.edu*

SICB Wide Symposium: Building Bridges from Genome to Phenome: Molecules, Methods and Models

Understanding the mechanistic basis by which genes give rise to both stability and variation in phenotypes is one of the Grand Challenges articulated by NSF. Accordingly, scientists in many disciplines are using a wide variety of organisms and experimental approaches to generate complex datasets at different levels of biological organization, all aiming to elucidate aspects of the genome-to-phenome framework. The goals of the Building Bridges Symposium, including invited speakers and related oral and poster complementary sessions are to build connections among ongoing research efforts, as well as to identify critical gaps and future needs to accelerate and facilitate this critical area of research. The Symposium is organized by members of NSF's Animal Genome-to-Phenome Research Coordination Network (AG2P RCN) to encourage networking across disciplines, gender, ethnicity, and professional ranks. Participant discussions at a concluding workshop will serve as the basis for a white paper identifying major gaps, key barriers and leading edges in the field of genome-to-phenome research.(NSF IOS 1927470)

30-3 BURNETT, NP*; BADGER, MA; COMBES, SA; University of California, Davis; *burnettnp@gmail.com*

Wind and canopy height affect honey bee flight performance in cluttered environments

Bees flying in natural habitats often encounter unpredictable wind conditions and cluttered vegetation – features that may adversely affect flight performance. Despite many studies examining how bee flight is affected by wind or by obstacle arrangement, we know little about the strategies that bees adopt when traversing spatially variable environments with both obstacles and wind. We examined the flight performance and behavior of honey bees (*Apis mellifera*) flying through a chamber with an array of vertical obstacles that did not extend to the ceiling, allowing bees to fly through the obstacles and/or above the obstacle "canopy." We varied the height of the array between trials (obstacles occupied 5% to 65% of the vertical space in the chamber) and tested bees flying upwind, downwind, and in still air. As obstacles grew taller in any wind condition, bees flew more slowly and took more time to traverse the array but did not change peak performance (maximum speed and acceleration). In each wind condition, bees adjusted the lateral component of their flight paths to stay farther from tall obstacles than from short obstacles. Finally, bees in wind did not adjust the vertical extent of their paths in response to array height, whereas bees in still air increased the total vertical space traversed – they extended the upper extent of flights (flew higher) but maintained the lower extent of flights as array height increased. Our results show that simple variation in obstacle features like height can interact with wind to alter bee flight performance and behavior. Thus, bees foraging in natural environments, and the pollination services they provide, may be affected more than previously thought by the interaction between wind and the configuration of surrounding vegetation.

72-1 BURRESS, ED*; WAINWRIGHT, PC; University of California, Davis; *edb0014@auburn.edu*

Are Oral and Pharyngeal Jaw Diversification Rates Correlated in Cichlid Fishes?

It has been appreciated for some time that the oral and pharyngeal jaws of fishes decouple prey capture and processing functions and their physical independence may permit considerable evolutionary independence and promote trophic diversity. However, the degree of evolutionary independence of these jaw systems is rarely estimated and continues to be poorly known. We tested the independence of oral and pharyngeal jaw diversification rates in New World cichlids. We measured functional morphological traits of the oral and pharyngeal jaws of 218 individuals representing 84 species. We assessed multivariate branch-specific rates of evolution using Bayesian inference in RevBayes. Overall, oral and pharyngeal jaw diversification rates were only weakly correlated. We found that only a few traits (15%) were more correlated between the jaw systems than expected based on Brownian motion. These tended to be negative correlations between traits associated with the biting strength of the pharyngeal jaws and the magnitude of oral jaw protrusion. This pattern may be due to a functional trade-off between suction feeding on evasive prey (e.g., fish) and sessile prey that requires intensive processing by the pharyngeal jaws (e.g., molluscs, algae). We found several instances of conflicting evolutionary patterns between the two jaw systems. Some piscivores exhibit dramatic diversification of oral jaw traits (i.e., Petenia), whereas others exhibit dramatic diversification of pharyngeal jaw traits (i.e., Cichla). Substrate sifting lineages consistently exhibited low diversification rates of both oral and pharyngeal jaws. Diversification of oral and pharyngeal jaws has largely been independent during the Neotropical cichlid adaptive radiation.

35-1 BURROUGHS, RW; University of Chicago; *rburroughs@uchicago.edu*

Modeling rodent tooth morphogenesis reveals constraints on mammalian tooth evolution

Mammal tooth morphology and function correlate strongly with dietary ecology, and convergence is a major feature of mammalian tooth evolution. Yet, function and ecology are insu cient to explain morphological diversi cation and convergence within mammalian molar evolution; suggesting that development and phylogeny also limit possible structural solutions to selective pressures. Here, I use *in silico* models and empirical studies of extant and fossil rodent teeth to identify morphogenetic rules that in uence molar morphology. Because rodents are the most diverse group of mammals with corresponding dental disparity they represent an excellent system for investigating how genetic interactions limit morphology. I find that lower molars are limited to a minimum of four cusps and a maximum of nine cusps. Multiple developmental pathways produce the same numbers of cusps, despite highly variable cusp morphologies, indicating the existence of limits on how morphological evolution can fill a morphospace defined by cusp numbers. These constraints are both developmental and phylogenetic in nature and the identifcation of their influence on rodent molar shape provides a framework for investigation of how tooth batteries evolved an array of functions despite fundamental structural limits. The data presented here increase predictability of cusp number and evolutionary outcomes of rodent cheek dentition.

94-2 BUSBY, MK*; DAVIDOWITZ, G; BRONSTEIN, JL; The University of Arizona, Tucson, AZ; *mkbusby@email.arizona.edu*

Thermolimit Respirometry Determines Relative CTmax Among Carpenter Bee Life Stages

Native bees are increasingly under threat from a wide variety of anthropogenic forces, including rising temperature. Warmer temperatures are already affecting organisms indirectly, through behavioral or range modification, or through adaptive plasticity as in advanced production of heat shock proteins. However, as temperatures approach organisms' critical thermal maxima (CTmax), they are more likely to directly impact survival, and understanding thermal tolerances will increase in importance. CTmax is most often measured in adult insects by observing knockdown while ramping temperature. However, in some cases it is the larval stages that are most vulnerable to thermal extremes, and bee larvae cannot easily be visually assessed for knockdown. Thermolimit respirometry solves this problem by measuring volume of CO2 in air that passes over an acclimated larva in an enclosed chamber. This allows for respiration to be monitored, and pinpoints time or temperature of death. *Xylocopa californica*, the desert carpenter bee, nests above ground, leaving its larvae particularly exposed to the effects of temperature. In the Sonoran Desert of southern Arizona, carpenter bees are near the southernmost and hottest part of their range, and possibly near the edge of their thermal geographic range. To assess thermal tolerance of during development, I used thermolimit respirometry on all larval and pupal stages. The least thermally tolerant life stage died at 52.6 degrees C. Record high local temperatures in southern Arizona have reached 47 degrees C. Measurements of developmental thermal tolerances at each life stage suggest that this critical pollinator is close to the maximum it can physiologically tolerate in a warming world.

130-2 BUSER, TJ*; SUMMERS, AP; SIDLAUSKAS, BL; Oregon State University, Corvallis, OR, University of Washington, Friday Harbor Laboratories, Friday Harbor, Washington; *busert@oregonstate.edu*

Stags of the Sea? Cranial Weapon Morphology in The Fish Subfamily Oligocottinae (Pisces; Cottoidea)

Many vertebrate groups have weaponized their skulls and, though some cranial weaponry aids defense, intraspecific combat appears to drive the evolution of these structures in most terrestrial cases. Equally impressive weaponry adorns aquatic vertebrates, such as the sculpins in superfamily Cottoidea. The skulls of these diverse fishes bear antler-like preopercular spines of remarkable variation, and the males of many species show intraspecific agonistic behavior during the breeding season. Do the evolutionary trends in weapon morphology of these fishes follow those observed in ungulates, beetles, and other fighting fauna? If so, we predicted that their spine shape would show ontogenetic change, sexual dimorphism, and asymmetry. We tested these predictions in members of the sculpin subfamily Oligocottinae by quantifying spine shape with 3D geometric morphometric techniques applied to reconstructions from micro-CT scans of members of each species. We found that sexual dimorphism is not apparent in the preopercular spine shape of oligocottines but ontogenetic change in shape is evident in several species and that asymmetry is common in all species. Interestingly, the direction of change across ontogeny is inconsistent across species, with the spines of some species becoming proportionally larger and more complex with age, while in others the spines become reduced. Asymmetry also showed higher than expected variation, with ~48% of preopercles having a shape more similar to the preopercle of a different individual than to the other side of their own body. Taken together, these results suggest that sculpins use their spines at least partially for agonism and combat, but also for defensive purposes, with possible trade-offs in some species across ontogeny.

117-6 BUSH, JM*; ELLISON, M; SIMBERLOFF, D; University of Tennessee Knoxville; *jbush15@vols.utk.edu*

Are brown anoles bullies? Insights into interactions between an invasive and native lizard species

Invasive species often displace native species that they closely resemble or compete extensively with. The mechanisms behind invaders' competitive success can vary widely, ranging from aggressive dominance over resources (interference competition) to superior resource utilization (resource competition). In this study, we looked for evidence of interference competition between an invasive lizard species, the brown anole (*Anolis sagrei*), and a closely related competitor that it displaces in the wild, the green anole (*A. carolinensis*). We housed captive populations of green anoles in large outdoor structures in Oak Ridge, Tennessee, and recorded their display behaviors and habitat use for 10 days. We then introduced brown anoles and recorded the green anoles' behaviors for another 10 days, looking for differences in pre- and post-invasion behaviors. We also recorded behavioral interactions between the two species. To serve as a density control, we repeated the experiment in a second enclosure using green anoles to "invade" the first populations. We found no evidence that brown anoles behaviorally dominate green anoles. Although brown anole males regularly displayed at green anoles, green anoles were generally uninterested in brown anoles and were more likely to interact with newcomers of their own species. Green anoles also did not change their display behaviors or activity levels in the presence of brown anoles. This study provides insights into how a native species responds to a closely related invasive competitor and indicates that social relationships between species do not necessarily reflect ecological relationships.

25-1 BUSTAMANTE, J*; AHMED, M; DANIEL, TL; University of Washington; *jorgebjr@uw.edu*

Restricting abdominal flexion yields poor flight performance in hawkmoths

Historically, the analyses of flight control and maneuvering have focused largely on aerodynamic forces generated by wings. Yet body (airframe) deformations may also be important and are often associated with maneuverability and flight control. Examples of non-wing maneuvering behaviors include changes in leg posturing as well as abdominal flexion. Abdominal flexion in particular may contribute to maneuverability because the abdomen comprises a large proportion of the weight of an insect. Thus, both active and passive changes in abdominal position physically redirect the inertia of the animal. Recent multi-body dynamics models also suggest abdominal motions during flight may contribute to maneuverability. If indeed such motions are critical, restriction of abdominal movement would yield poorer flight performance. To test this hypothesis, we glued a carbon fiber rod between the thorax and abdomen, thereby restricting abdominal flexion during flight for hawkmoths (*Manduca sexta*). The moths were tasked with feeding from a 3-D printed flower in natural light and temperature conditions. Without any modifications, 45 of 89 animals flew successfully and approached the flower. Only 5 of 38 trials across 29 moths flew successfully and approached the test flower. We also developed a sham treatment with the same weight of carbon fiber but severed into two pieces—one piece glued to the thorax, and the other glued to the abdomen allowing abdominal flexion. Of these sham experiments, 8 of 16 trials across 12 moths. These results suggest that abdominal flexion is necessary for flight control in hawkmoths. Our results also suggest multiple actuators are critical for flight control in insects.

80-7 BUTLER, MW*; ARMOUR, EM; MINNICK, JA; ROSSI, ML; SCHOCK, SF; BERGER, SE; HINES, JK; Lafayette College, Easton PA; *butlermw@lafayette.edu*

Both Circulating Corticosterone Levels and Heme Oxygenase Expression Are Correlated With Circulating Triglyceride Levels in House Sparrows

When exposed to stressors, animals respond by secreting glucocorticoid hormones such as corticosterone (CORT), thus affecting a variety of physiological processes, including lipid metabolism. However, the factors regulating lipid metabolism, particularly during acute (i.e., short-term) stressors, are not well-characterized. To investigate one putative mechanism, we examined how expression of the enzyme heme oxygenase (HO), which primarily converts heme into biliverdin, changes during an acute stressor. Because HO also has links to decreased levels of triglycerides, we tested the hypothesis that an acute stressor increases HO expression, which would concomitantly decrease circulating lipid levels. House sparrow (*Passer domesticus*) nestlings exposed to a stressor had reduced circulating triglycerides consistent with an increase in rate of gluconeogenesis during an acute stressor. Concentrations of triglycerides were also negatively correlated with HO expression in the liver, which is consistent with mammalian studies. However, contrary to our predictions, exposure to a stressor did not affect HO expression, or biliverdin concentration in liver, spleen, or kidney. Overall, our results support a link between HO expression and triglyceride levels, though the molecular pathways connecting these two metrics still need to be elucidated.

18-4 BUTLER, JM*; HERATH, E; WHITLOW, SM; RIMAL, A; MARUSKA, KP; Louisiana State University; *jbutl48@lsu.edu*

Honey, I Ate the Kids: Role of Galanin in Maternal Care, Infanticide, and Energetics in a Mouthbrooding Fish

Galanin is a conserved neuropeptide involved in parental care and feeding. Ablation of preoptic area (POA) *gal* neurons induces infanticide behaviors in mice, while activating POA *gal* neurons promotes parental care. Within the mammalian arcuate nucleus (Arc), *gal* acts to promote feeding. Mouthbrooding is an extreme form of parental care in which the parent carries the developing offspring in their buccal cavity for the duration of development. In the cichlid fish *Astatotilapia burtoni*, females brood their young for ~2 wks, during which time they refrain from eating. After release of juveniles, females perform maternal care by collecting them into their mouth when threatened. Maternal care is observed for several days post-release, but females will cannibalize their brood after ~5 days. As such, maternal care and feeding are integrally linked. To examine the role of *gal* in feeding and maternal care, we collected 5 groups of females: (1) mouthbrooding for 12 days; (2) starved for 12 days; (3) fed for 12 days; (4) females displaying post-release maternal care; and (5) females who cannibalized ~50% of their brood. In *A. burtoni*, *gal* is expressed in the POA and lateral tuberal nucleus (NLT, Arc homolog). Although the number of *gal*-expressing cells does not vary among conditions, activation of *gal* neurons is condition-dependent. Females displaying maternal care have more activated POA *gal* neurons. In contrast, fed females have high activation of NLT *gal* neurons, with little to no activation in brooding fish. Preliminary results suggest that females displaying infanticide have little to no activation of POA *gal* neurons. Overall, these data suggest a functional conservation of *gal* across vertebrate taxa with POA *gal* neurons promoting maternal care and NLT *gal* neurons promoting feeding.

21-3 CADE, D E*; CAREY, N; DOMENICI, P; POTVIN, J; GOLDBOGEN, J A; Stanford University, Scottish Association of Marine Science, IAS-CNR, Istituto per l'Ambiente Marino Costiero, Saint Louis University; *davecade@stanford.edu*

Predator-informed looming stimulus experiments reveal how large filter feeding whales capture highly maneuverable forage fish

Forage fish have been involved in evolutionary tug-of-wars with predators for more than 100 million years yielding finely balanced predator-prey interactions with thin margins for error. Engulfment predation by gigantic filter feeding whales, in contrast, is a relatively recent (< 5 Ma) phenomenon that typically occurs at extreme predator-prey size ratios that mitigate the effect of prey escape responses (e.g. microphagy on krill). Rorqual whales, however, also commonly hunt forage fish whose performance capabilities suggest that they should easily evade whale-sized predators. To address this paradox we determined, in a laboratory setting, when individual anchovies initiated escape from virtually approaching whales, then used these results along with in vivo humpback whale attack data to model how predator speed and engulfment timing affected capture rates. Anchovies were found to respond to approaching visual looming stimuli at expansion rates that give ample chance to escape from a sea lion-sized predator, but humpback whales could capture as much as 40-50% of a school at once because the increase in their apparent size does not cross their prey's response threshold until their jaws are already rapidly expanding. Humpback whales are thus incentivized to delay engulfment until they are very close to a prey school, even if this results in higher hydrodynamic drag. This potential exaptation of a microphagous filter feeding strategy for fish foraging enables humpback whales to achieve nearly 7x the energetic efficiency (per lunge) of krill foraging, allowing for flexible foraging strategies that may underlie their ecological success in fluctuating oceanic conditions.

13-7 CALEDE, J; The Ohio State University, Marion, OH; *calede.1@osu.edu*

Evidence for a Semi-Aquatic Ecology in a 30-Million-Year-Old Beaver and the Evolution of Locomotion in Castoridae

The family Castoridae is today represented by only two species, the Eurasian and the North American beavers. Both animals are large semi-aquatic rodents. The fossil record includes many more species; 70 are known from North America alone, some in deposits as old as 37 million years. The bulk of this diversity arose 30 million years ago with the evolution of many burrowing species. The oldest North American semi-aquatic rodent, the beaver *Monosaulax*, is 18.8 million years old. Despite the wealth of data on the locomotion of many burrowing beavers of the Oligocene and the semi-aquatic ones of the mid-Miocene to today, castorid evolutionary ecology remains enigmatic; the oldest species of beavers are known only from fragmentary craniodental remains. I here present the oldest postcranial remains of an anchitheriomyine beaver dated to 30 million years ago discovered in Montana. The dentition indicates that this animal is a new *Microtheriomys* species. I use a multivariate analysis of astragalus shape to infer its locomotory ecology. Based on a training set including 259 specimens representing 117 species of extant rodents and fossil beavers with known locomotion, I determine that *Microtheriomys* represents the oldest semi-aquatic rodent in North America. I also provide the first quantitative determination of the locomotion of three additional beaver species and the castoroid *Eutypomys*. I include the results of this ecomorphological analysis into an updated phylogenetic framework for 33 castoroid species with known locomotion. My ancestral character state reconstruction shows the evolution of the semi-aquatic ecology only once from terrestrial ancestors but hints at a more complicated evolution of burrowing.

125-1 CAMPOS, S M*; ROJAS, V; WILCZYNSKI, W; Georgia State University, Universidad del Bío-Bío, Concepción; Universidad Catolica del Maule; *scampos1@gsu.edu*

Arginine vasotocin stimulates chemical communication and social behavior in Anolis carolinensis lizards

Social interactions in nonmammalian vertebrates are modulated by arginine vasotocin (AVT), which functions similarly to its mammalian homologue, vasopressin. AVT impacts the performance of and response to visual signals in reptiles, but whether AVT also operates within the chemosensory system as it does in mammals is unknown, despite social odors being potent modifiers of aggressive and reproductive behavior. Previous studies in green anoles (*Anolis carolinensis*) linked elevated levels of exogenous AVT in males (AVT-males) to lower rates of aggressive visual displays, whereas untreated females visually displayed to AVT-males more than to saline-treated Control-males. Here, we test whether exogenous AVT in Resident-males impacts the chemosensory or locomotor behavior of conspecifics (Intruders). We injected Resident-males with either AVT or a Control solution, and after 10 mins alone in their home tanks, we presented Resident-males with an untreated Intruder (male or female) for 30 mins. We found that Intruder-males performed more chemical behavior towards AVT-males than to Control-males, whereas AVT-males responded with a chemical display to Intruder-females faster than did Control-males. In contrast, visual behavior did not differ between treatment groups for either Resident-males or Intruders in this experiment. Our results demonstrate for the first time that AVT modulates chemosensory behavior in reptiles, having important evolutionary implications regarding multimodal communication and the mechanisms used by AVT to modulate animal interactions.

34-4 CANNON, JT*; KOCOT, KM; VARNEY, RM; EERNISSE, DJ; SPEISER, DI; OAKLEY, TH; UC Santa Barbara, University of Alabama, Cal State Fullerton, University of South Carolina; *joie.cannon@gmail.com*

Target-capture phylogenomics of Polyplacophora and the origins of shell eyes

Chitons possess clusters of sensory cells called aesthetes within their eight overlapping shell plates. In some polyplacophoran species within a large unresolved subgroup, Chitonina, aesthetes are modified to include an eyespot, and in others, aesthetes are present in addition to eyes with a lens and retina. To address the evolution of complexity in chiton eyes, it is necessary to phylogenetically test the relationships between chitons with eyespots and chitons with lenses. Relationships within Chitonina have been difficult to resolve with traditional molecular markers, limiting our ability to test evolutionary hypotheses. To enable us to use ethanol-preserved collections, we took a target-capture approach. We designed a set of 19,980 probes using transcriptome data and predicted exon boundary information using three mollusk genomes (*Lottia*, *Octopus*, and *Crassostrea*). Preliminary maximum likelihood analyses show strong support for super-family relationships, and suggest the possibility of multiple origins for lenses in chitons. However, hypothesis testing and ancestral state reconstructions are necessary to further investigate this result.

S8-8 CAPANO, JG*; BRAINERD, EL; Brown University; *john_capano@brown.edu*

Reaction Forces and Rib Function During Locomotion in Snakes

Locomotion in tetrapods involves coordinated efforts between appendicular and axial systems, as limbs generate ground reaction forces (GRFs) that are transmitted to the axial system. In the absence of limbs, snakes experience locomotor GRFs in fundamentally different ways than their limbed-lizard ancestors. Without GRFs from limbs, the epaxials of early snakes were no longer required to stabilize against torsional GRFs and were modified to generate propulsive forces. These forces must be transmitted into the environment and since snakes locomote on their bellies, their ribs must play an inherent role in GRF transmission. Snakes locomote with at least two kinematic styles: (1) with no static contact points, i.e. lateral undulation, or (2) with static contact points, i.e. concertina, rectilinear, climbing, and sidewinding. Rib motions are crucial to this locomotor versatility: our XROMM work and previous studies show that ribs change cross-sectional body shape, deform to environmental irregularities, provide synergistic stabilization for other muscles, and differentially exert and transmit forces to control propulsion. Ribs are also used for lung ventilation in snakes, and we found that snakes are able to independently and regionally control ventilatory motions. We suggest that snakes co-opted the rib motions of ventilation to dynamically and passively participate in their diverse locomotor modes. Hence, removal of the constraints of limbed locomotion and new mechanics of limblessness may have influenced snake evolution and enabled snakes to modify rib motions to contribute to locomotion in innovative ways. Future comparisons with other limbless lizard taxa are necessary to tease apart the mechanics and mechanisms that produced the locomotor versatility observed within Serpentes.

50-1 CAPANO, JG*; CIERI, RL; WELLER, HI; BRAINERD, EL; Brown University, University of Utah; *john_capano@brown.edu*

Modular Lung Ventilation in Snakes

Most squamates rotate vertebral and sternal ribs to ventilate their lungs, whereas snakes lack sternal ribs and use only vertebral ribs to breathe. Rib rotations are described about a dorsoventral axis (bucket), a craniocaudal axis (caliper), and a mediolateral axis (pump). Our objectives were to use XROMM to quantify rib rotations of *Boa constrictor* during ventilation and compare their kinematics and musculature to three previously studied squamates: *Iguana iguana*, *Varanus exanthematicus*, and *Salvator merianae*. We compared the relative contribution of each rotational axis to overall rib motion by fitting a linear mixed effects model to the variance-normalized centroids. We found that *B. constrictor* breathe with predominantly bucket, with moderate caliper and substantial pump, that bucket and pump are opposite in polarity, and that these motion patterns were significantly different from *I. iguana* and *S. merianae*. In contrast, we found the motions of *B. constrictor* were not significantly different from *V. exanthematicus* and that both use cranial pump rotations during inhalation, opposite the other species. These similarities appear related to derived muscles in *B. constrictor* and *V. exanthematicus*: both have accessory costal muscles that run cranially from each rib to the next cranial vertebrae, i.e. levator costae, whereas the other species do not. Our data suggest that snakes evolved such accessory muscles to breathe without a pectoral girdle, a structure that may synergize with intercostals to rotate the ribs of most squamates. These accessory levator costae appear to enable snakes to breathe with spatially disparate regions of their body. This modular ventilation mechanism may have permitted the evolution of constriction and large prey ingestion in snakes and been a prerequisite to their extensive radiation.

61-3 CAREY, HV*; REGAN, MD; CHIANG, E; SUEN, G; ASSADI-PORTER, F; University of Wisconsin-Madison; *HANNAH.CAREY@WISC.EDU*

Stable Isotope Assisted Labeling Reveals Seasonal Influence on Microbial Metabolite Incorporation in Ground Squirrels

Diet exerts a major influence on the composition and function of the gut microbiota and, therefore, host-microbial symbiosis. Thirteen-lined ground squirrels have seasonal metabolic cycles comprised of summer feeding - providing substrates for squirrel and microbiota metabolism - and winter fasting - when hibernators metabolize primarily stored fat and microbes have access only to host-derived metabolic substrates (e.g., mucins). To assess how seasonal dietary change affects the hibernator-gut microbe symbiosis, we used stable isotope assisted metabolomics to assess the capacity of the gut microbiota in degrading substrates and generating metabolites that are incorporated into the squirrel metabolome. After oral gavage of active season and hibernating (aroused) squirrels with ^{13}C-inulin (a substrate mammals cannot degrade), changes in ^{13}C:^{12}C (^{13}C) are monitored in exhaled CO_2. We found that increases in ^{13}C after ^{13}C-inulin gavage are high and similar in spring and summer squirrels, lower in aroused hibernators, and abolished when squirrels are pretreated with microbiota-depleting antibiotics. NMR analysis reveals multiple ^{13}C-labeled metabolites in gut contents, blood and liver of summer and hibernating squirrels including short chain fatty acids, -hydroxybutyrate and carnitine, among others. Cluster analysis (PLSDA) indicates that liver ^{13}C-metabolites separate by season and by presence/absence of antibiotics. This approach provides a pathway for a molecular-based exploration of the seasonally changing hibernator-microbe symbiosis. Supported by NSF 1558044.

38-6 CARRIER, DR*; BOYNTON, AM; CARRIER, ; University of Utah, School of Biological Sciences, Salt Lake City, UT; *carrier@biology.utah.edu*

The Neck is Part of the Human Core

The axial musculoskeletal core of tetrapods provides a stable base from which limbs exert forces on the environment. The human core is generally thought to be composed of the axial muscles that lie between the diaphragm and pelvic floor and to provide stability for the hindlimbs (i.e., legs). We hypothesized that the human core is actually composed of all the axial muscles extending from the pelvis to the skull. To test whether cervical muscles play a role in core stabilization, we used surface electromyography to measure the activity of a set of neck and jaw muscles during force manipulations of maximum effort counter-movement jumps. To determine whether cervical muscles function during jumps to control posture of the head or to assist in stabilization of the pelvis against the moments applied by the leg retractor muscles we compared muscle activity during control jumps to jumps in which we (1) reduced peak accelerations by approximately 30% by pulling downward on the subject's hips with elastic tethers, and (2) increased the mass of the head by approximately 100%. When subjects jumped with increased downward force, or with mass added to their heads, maximum and integrated activity of neck and jaw muscles was not different from that recorded during control jumps. These results do not support the hypothesis that the superficial muscles of the neck (i.e., those accessible with surface electrodes) play an important role in postural support of the head during active movement. Instead, our results suggest that these neck muscles contribute to core stability in response to moments imposed on the pelvis by the extrinsic muscles of the leg. The observation that neck muscles provide stability for the legs of humans has implications to the locomotor function of the tetrapod neck, prevention of spinal injury, and treatment of chronic cervical and back pain.

60-6 CARRUTHERS FERRERO, A*; OZKAN AYDIN, Y; GOLDMAN, DI; Georgia Tech; *alexandra.carruthers@gatech.edu*
Lateral bending and buckling aids earthworm locomotion in confined environments
Earthworms locomote in confined spaces and underground via retrograde peristaltic gaits where a transient substrate anchor is formed by the contraction of longitudinal muscles. Here, via laboratory studies of the earthworm *Lumbricus terrestris*, we reveal how the locomotion ability of the worms is enhanced via lateral bending and buckling of body segments. Depending on absence or presence of contact between the animal's body and environment, worms control the shape of their slender-flexible bodies (usually bending tip or tail) to generate thrust and maneuver in three dimensions. To study the benefits of this behavior, we allowed the earthworms (L = 26.95 ± 6.18 cm and m = 7.49 ± 2.04 g, n = 10) to crawl in a large acrylic tube (d = 1.0 cm, l = 1 m, d > worm diameter) while varying the tube angle from 0 to 90°. We calculated the average body length per gait cycle (BL/cyc) over several cycles. At a 0° incline, the worms had the largest (0.201 ± 0.075) BL/cyc and mostly moved by peristaltic gait. The worms had the lowest (0.076 ± 0.016) BL/cyc at a 90° incline but could still climb without significant slipping. At higher degree angles, such as 75 and 90°, the body bending was more prevalent than at lower angles, providing extra anchoring points for the forward locomotion and reducing the occurrences of slipping. Our results reveal that adequate control of body shape can help limbless terrestrial animal locomote in diverse environments. Moreover, this movement strategy has aided design of the control system of a soft earthworm-inspired robot.

74-7 CARTER, AW*; SHELDON, KS; University of Tennessee; *acarte82@utk.edu*
The Climate Variability Hypothesis Predicts Thermal Plasticity Across Life Stages of Onthophagus taurus Dung Beetles
Most organisms live in thermally variable environments and climate change stands to increase this variation. However, studies often utilize constant temperatures and focus on a single life stage, which may undermine the accuracy of climate change predictions. One hypothesis that has been utilized to help predict organismal responses to temperature fluctuation is the climate variability hypothesis (CVH), which posits that increased temperature variation selects for increased thermal plasticity. Though the CVH has been tested along natural temperature gradients (e.g. latitude), it may also predict thermal plasticity across discrete life stages that experience varying degrees of thermal fluctuation. Here, we test the CVH across life stages of *Onthophagus taurus* dung beetles; pupa develop underground buffered from temperature extremes, whereas adults also inhabit open fields and dung pats with substantial temperature fluctuation. We reared F_2 full-siblings in either high (24 ± 8°C) or low (24 ± 4°C) temperature fluctuation treatments and quantified thermal plasticity at pupal and adult life stages. We compared shifts in thermal sensitivity of metabolism among treatments and life stages by measuring CO_2 production at 15, 20, 25, and 30 °C in pupae and adults. We found that adults exhibited thermal plasticity and pupae did not, supporting the CVH. In response to thermal variability, adults exhibited metabolic depression, which should conserve energy in fluctuating temperatures. This novel application of the CVH underscores the importance of considering stage-dependent thermal responses in climate change forecasting; predictions that are not based on the most critical life stage may overestimate the likelihood of persistence.

4-4 CASS, JA*; WILLIAMS, CD; KNIJNENBURG, TA; THERIOT, J; Allen Institute for Cell Science, Seattle, Allen Institute for Cell Science, Seattle and University of Washington, Seattle; *juliec@alleninstitute.org*
A Bayesian framework for the detection of diffusive heterogeneity
Cells are crowded and spatially heterogeneous, complicating the transport of organelles, proteins and other substrates. One aspect of this complex physical environment, the mobility of passively transported substrates, can be quantitatively characterized by the diffusion coefficient: a descriptor of how rapidly substrates will diffuse in the cell, dependent on their size and effective local viscosity. The spatial dependence of diffusivity is challenging to quantitatively characterize, because temporally and spatially finite observations offer limited information about a spatially varying stochastic process. We present a Bayesian framework that estimates diffusion coefficients from single particle trajectories, and predicts our ability to distinguish differences in diffusion coefficient estimates, conditional on how much they differ and the amount of data collected. This framework is packaged into a public software repository, including a tutorial Jupyter notebook demonstrating implementation of our method for diffusivity estimation, analysis of sources of uncertainty estimation, and visualization of all results. This estimation and uncertainty analysis allows our framework to be used as a guide in experimental design of diffusivity assays.

61-2 CAVIEDES-VIDAL, E*; BRUN, A; MAGALLANES, ME; BARRET-WILT, GA; KARASOV, WH; Consejo Nacional de Investigaciones Científicas y Técnicas - Universidad Nacional de San Luis, Universidad Nacional de San Luis, Consejo Nacional de Investigaciones Científicas y Técnicas, University of Wisconsin-Madison; *enrique.caviedes@gmail.com*
Dietary Adaptation to High Starch Involves Increased Abundance of -Glucosidase and its mRNA
Dietary flexibility in digestive enzyme activity is widespread in vertebrates, but mechanisms are poorly understood. Fragmentary evidence indicates that laboratory rats modulate intestinal -glucosidase (AG) activity mainly by relying on rapid increase in enzyme transcription followed by translation and translocation to the intestine s apical, brush border membrane (BBM). We performed the first unified study of this overall process, relying on activity, transcriptomic and proteomic data from the same animals. We used as our model nestling house sparrows (Passer domesticus), which increase their intestinal AG activity as they switch naturally from low starch insect diet to higher starch seed diet. Twenty-four hours after a switch to a high starch diet, intestinal AG activity and mRNA were increased. The protein sucrase-isomaltase (SI), which is responsible for all maltase and sucrase activity, was the only hydrolase increased in the BBM, and its abundance and activity were positively correlated. This is the first demonstration that birds may rely on rapid increase in enzyme abundance when adjusting to high starch diet.

81-4 CEJA, AY*; WAY, MJ; KANE, SR; University of California, Riverside, NASA Goddard Institute for Space Studies, New York, NY; *aceja005@ucr.edu*

PEACH: The Physiology Exoplanet Astroecology model for Characterizing Habitability

A primary objective of astrobiology is to identify habitable exoplanets. Here, I apply an integrative approach between astrophysics, climate modeling, and ecophysiology to explore the relationship between alien environments and terrestrial life. I discuss the development of a novel system to be used as a tool to assess the habitable regions on exoplanet surfaces. In this model, simulated exoplanet environments are convolved with a real biological layer. Exoplanet environments are simulated using the climate model, Resolving Orbital and Climate Keys of Earth and Exoplanet Environments (ROCKE-3D, Way et al. 2018). ROCKE-3D is a fully-coupled 3-dimensional oceanic-atmospheric general circulation model (GCM) featuring interactive atmospheric chemistry, aerosols, the carbon cycle, vegetation, oceans, sea ice, and land surface components. The GCM output is coupled in the astroecology model with empirically-derived thermal performance curves of 1,627 cell strains representing extremophiles from all six Kingdoms, termed the biokinetic spectrum for temperature (Corkrey et al. 2016). The spectrum arises from a meta-analysis of cellular growth rate as a function of temperature. In this agent-based model, created with the software NetLogo, the survivability of an organism is determined by its thermal response to simulated temperatures. This model can be applied to predict exoplanet conditions compatible with terrestrial-based thermophysiology, as well as surface maps highlighting potentially habitable regions. Life, however, is dependent upon multiple variables including the presence of liquid water, nutrient content, and an energy source. Caveats of the methodology and application of results are discussed with implications for observable biosignatures.

6-2 CELLINI, BO*; MONGEAU, J-M; The Pennsylvania State University; *boc5244@psu.edu*

Flexible visual control of gaze via head saccades in Drosophila flight

Flying insects guide their body by generating smooth movement and rapid, ballistic turns, named "body saccades". After the onset of a body saccade, an ensuing head saccade presumably helps to stabilize gaze more rapidly by reducing the period of motion blur. Whereas the visual control of body saccades has been described previously, less is known about the dynamics and control of head saccades and whether head saccades can operate independently from the body. Specifically, can head and body saccades be uncoupled? We investigated yaw head saccade dynamics and control during the optomotor response in rigidly tethered *Drosophila* in virtual reality. Head saccade dynamics were stereotyped for a moving panorama, however saccade speed and rate decreased for a static panorama, suggesting influences of visual motion. Head saccades were almost entirely anti-directional with respect to visual motion direction, suggesting that they act to 'reset' visual gaze. Reset saccades allow flies to maintain low retinal slip speed as flies are physically unable to maintain a fixed velocity due to the restricted range of motion in yaw. Head saccades were triggered when the temporal integral of the retinal error reached a threshold, rather than by absolute retinal position error. This result suggests an integrate-and-fire trigger. More than 60% of head saccades were triggered independently of Δwingbeat amplitude spikes, suggesting uncoupled trigger of head and body saccades. For synchronous wing-head saccades, the wings led the head by 5 ms, but approximately 25% of head and wings saccades occurred in opposite directions. Our results point to convergent mechanisms for visual control of head and body saccades. We propose a parallel control system for visual control of head and body saccades.

127-5 CERDA, PA*; CROWE-RIDDELL, J; LARSON, JG; NAGESAN, R; CALLAHAN, S; RABOSKY, DL; DAVIS RABOSKY, AR; University of Michigan; *pacerda@umich.edu*

Comparisons of Interspecific and Intraspecific Variation in Rear-Fanged Snake Venom Expression

Understanding the evolution of a highly variable trait among species can be difficult if an inaccurate trait value is assigned. One such trait that contains tremendous variation is venom, a toxic substance typically used by organisms for prey capture and/or defense. Variation in venom composition among snake species is attributed to strong selective pressures acting on venom genes and gene families which result in restructured gene families and changes in expression. Furthermore, venom is known to be variable within a species, often due to geographic variation among populations. Additionally, ontonogenic shifts in venom composition and short-term changes in venom expression after feeding contribute to variation in venom within an individual. Due to these sources of intraspecific variation, it might be difficult to make generalized statements about the venom composition of a single species and make comparisons across species. However, it is also possible that within-species variation is fairly low despite sampling variation in location, age, or feeding status. Here I describe the venom expression profiles of several species of rear-fanged snakes, which until recently had been largely understudied, and compare among and within species variation to determine if an accurate trait value can be assigned regardless of potential sources of variation.

65-2 CHAMBERS, NM*; WILLIAMS, CM; West High School, University of California, Berkeley; *chambers.nikki@tusd.org*

The Beetle Project: Bringing Authentic Research Into High School Classrooms

The future of any scientific discipline depends on nurturing understanding of both discipline-specific core ideas and the nature of scientific thought in the next generation of scientists. Education/outreach continues to be emphasized as a core component of research grants. Efforts to bridge the formidable gap between K-12 science education, and scientific research and teaching at the post-secondary level, benefit from active collaboration between researchers and K-12 teachers. A successful exemplar is the "Beetle Project" spearheaded by the Williams Lab at the University of California, Berkeley. A two-month teacher-as-researcher experience funded by the NSF/SSE has yielded a published, NGSS-aligned instructional module using insects as a model system to illustrate biological impacts of climate change. The curricular goal is engaging students with a range of hands-on and minds-on activities that increase their understanding of how science works, evolutionary processes, and the impacts of climate change. We will model the curriculum, present ongoing results of implementation in high school classrooms, and discuss the benefits to both students and teachers of bringing authentic research into the classroom. Module components include: 1) a set of whole-organism/behavior and molecular lab activities using ladybird beetles; 2) a paper-and-pencil Data Nugget activity; and 3) an illustrated case study on the willow leaf beetle research that inspired the module, with extension materials for AP classrooms. The full module is hosted on the UC Berkeley Understanding Evolution website (https://tinyurl.com/y6bk9pzc). Detailed lesson plans suggest different scaffolding options for students from a variety of levels (middle school – AP Biology) and for classrooms with greater or lesser access to lab resources. We are partnering with teachers to develop, test, and disseminate the modules.

S2-9 CHAMPAGNE, FA; University of Texas at Austin, Austin, TX; *fchampagne@utexas.edu*
Epigenetics and Reproductive Trade-offs in Response to Stress
Exposure to stress during development can shape a broad range of phenotypic outcomes. In addition to programming response to stressors, these early experiences shape later life reproductive outcomes. Theoretical explorations of this phenomenon, drawing on life-history theory, suggest that both within-species and across-species variation in reproductive strategies would be predicted to be influenced by ecological factors indicative of resource availability and stressors (both physical and social). Endocrine, neurobiological and molecular studies suggest that the quality of the early environment – particularly qualities indicative of stress or threat - can have lasting effects on multiple biological systems. Epigenetic changes induced by these environmental exposures may mediate the link between stress and subsequent phenotypic outcomes. We have examined the epigenetic, neurobiological and behavioral consequences of early life stressors in rodents (rats and mice) with correlational studies also conducted in humans. Prenatal stress is associated with increased stress responsivity, altered neurodevelopmental trajectories and impairments in social and reproductive behaviors. These phenotypic outcomes are predicted by epigenetic variation in the placenta and associated with region-specific changes in gene expression and DNA methylation in the brain. Postnatal exposure to low vs. high stress environments is predictive of reduced maternal behavior and increased sexual behavior in later life. Altered DNA methylation of hormone sensitive genes in brain regions that regulate reproductive behavior may account for these effects. Future work on the trade-offs in phenotypic outcomes and the molecular mechanisms that shape these outcomes may provide further insights into the within and across-generation emergence of stress-induced reproductive strategies.

51-6 CHANDRASEGARAN, K; WYNNE, N; VINAUGER, C*; Virginia Tech, Blacksburg, VA; *vinauger@vt.edu*
Visual Avoidance Behavior in Mosquito Larvae and Adults
Mosquitoes are the deadliest animals on earth and the diseases they transmit, such as zika, chikungunya and malaria, are responsible for at least one million deaths each year. Current strategies to control populations of disease vector insects are being challenged, in part because of rising insecticide resistance. Therefore, novel strategies, informed by improved knowledge of mosquito biology, are urgently needed. However, progress in identifying new targets for vector control has been hindered by a lack of understanding of the mechanisms that regulate mosquito-host interactions. Multiple sensory modalities enable mosquitoes to navigate through their environment and locate suitable hosts. Although mosquitoes' responses to olfactory cues have been well characterized, comparatively less is known about the way visual stimuli are processed and integrated by these insects. Furthermore, in most cases, the visual sense of mosquitoes has been investigated in the context of their attraction to host-like objects. But visual cues can also signal threats such as a swatting hand. Leveraging a combination of freely moving and tethered preparations, we analyzed the avoidance behavior of multiple mosquito species to threat-like stimuli across developmental stages. Electrophysiological recordings in tethered-behaving individuals were then performed to unravel the underlying neural mechanisms. The significance of these results will be discussed relative to the design of control tools.

90-4 CHAN, KYK*; WONG, E; WONG, JY; XU, K; KOEHL, MAR; Swarthmore College, Hong Kong University of Science and Technology, Academia Sinica, University of California, Berkeley ; *kchan1@swarthmore.edu*
Hydrodynamics of barnacle nauplii shape evolution of body form
Many types of zooplankton have spines but their functional consequences are debated. Using naupli larvae of barnacles, we studied the hydrodynamic effects of spines and their impact on swimming, sinking, and feeding performance of these microscopic animals operating in a size and speed range at which the fluid dynamics is poorly understood. Barnacle nauplii are unique among crustaceans by having frontal horns and some have long tail spines. Naupliar form can range from parasitic species whose naupli have globular bodies with small horns and tails, to gooseneck species whose nauplii have slender bodies and long, fine horns and tail spines. Such diverse forms enable us to study the effects horn, tail, and body shape on hydrodynamic performance. By measuring hydrodynamic forces and torques on, and flow fields around dynamically-scaled physical models of nauplii for which morphology can be altered, we tested the hypothesis that long body extensions (horns and tail spines) increase drag on and resist tumbling by nauplii, These model experiments and our high-speed, micro-Particle Image Velocimetry analysis of live larvae showed that a globular body with small horns and tail spines (the parasitic *Polyascus plana*) experience lower drag and disturb the water less when they move than does a slender body with long tail spines and horns (the gooseneck *Lepas sp.*).Low-drag shapes can enhance swimming performance, whereas high-drag shapes can reduce sinking rates and enhance feeding by acting as sea anchors so flapping appendages can sweep through the water to filter particles. Thus, tradeoffs between different ecological functions impose constraints on the evolution of larval forms.

67-1 CHANG, ES*; GONZALEZ, P; SCHNITZLER, CE; BAXEVANIS, AD; NHGRI/NIH, U. Florida; *sally.chang@nih.gov*
Diverse patterns of human disease gene emergence and loss across the Metazoa
The increasing ease of generating genome-scale data has led to a huge increase in the number of organisms being developed as models for studying human biology. Given this increase, it is important to evaluate whole-genome sequence data from a broad array of organisms to determine their possible utility in investigating a particular human phenotype or disease. To address this, we have taken an evolutionary genomics approach to investigate patterns of disease-gene emergence and loss across the Metazoa, with a particular focus on these patterns in non-bilaterians, a group that is relatively underexplored in relation to questions in human health. We have identified orthologs across 49 taxa using a phylogenetically aware algorithm, then used these data to infer the age of origin of orthogroups containing a known human disease gene. On average, human disease genes appear to have a more ancient origin than the human genome as a whole, suggesting that a broad range of metazoans may be suitable genomic models for understanding these phenotypes. Some non-bilaterians, such as the cnidarians, have approximately the same percentage of these disease genes as some well-established model organisms, suggesting that they may be more suitable models when studying certain genetic pathways. Our work confirms that distinct subclasses of genes have distinct evolutionary histories, reinforcing the importance of considering different taxa in the context of specific biological questions. Finally, we have investigated the effects of methodological choices such as whether or not to include splice variation on our final inferences. Our results suggest that a broader range of metazoans than those currently used may prove to be useful for understanding the genomic bases of human diseases.

139-4 CHANG, B*; NOWAYTI, W; HSIEH, ST; Temple University; *brian.chang@temple.edu*

Force response of climbing sand dunes

Running up a sand dune is a challenging task due to several factors. First, sand fluidizes when an external force exceeding the material yield stress is applied. Second, at the angle of repose, the sand pile is unstable, such that small perturbations will cause fluidization. Ongoing studies in the lab show that sand specialist lizards exhibit lower running speed decrements than desert generalist lizards when running up inclined sand. Preliminary evidence indicates that impact angles of the foot relative to the sand differ between sand generalists and specialists, suggesting that differences in foot and leg movement can have dramatic effects on force generation. In this study, we experimentally examine the impact force normal to a flat plate against a bed of poppy seeds (~1 mm diameter). We test a range of impact speeds (0.01-1.2 m/s), substrate angles (0-40 degrees from the horizontal), and impact angles (0-40 degrees from gravity). When comparing the magnitude of force acting normal to the plate at varying substrate and impact angles, two regimes become apparent: 1) the gravity regime and 2) the inertial regime. In the gravity regime, the weight of particles dominates granular motion and causes fluidization of the substrate which correlates to divergences in the force depth relation when comparing force responses between substrate angles and intrusion angles. However, in the inertial regime, particle motion is dominated by the inertia of the intruder, which results in the force depth relation to converge between substrate and intrusion angle. Based on these results, we discuss the implications for the efficacy of lizards running up sand dunes.

37-1 CHAPMAN, BR*; WILSON, LE; Fort Hays State University, Hays, KS; *brchapman@mail.fhsu.edu*

Predicting habitat preferences of Hesperornis (Aves: Hesperornithiformes) in the Western Interior Seaway through occupancy modeling

In the Late Cretaceous, North America was divided by the Western Interior Seaway (WIS), a shallow epicontinental sea. Native vertebrate life included marine reptiles, fish, and seabirds such as *Hesperornis*, a flightless avian with a foot-propelled diving lifestyle similar to cormorants. Occupancy modeling predicts occupancy and detection probabilities for the taxa of interest at sampled sites and is used here to understand environmental and biological factors influencing *Hesperornis* distribution. Campanian WIS vertebrate occurrences and sedimentological data were gathered for the United States and Canada from peer-reviewed literature, museum collections, and online databases. Occurrences consist of taxa found with and without *Hesperornis* and include known predators and other contemporaries. The statistical modeling software PRESENCE was used to create and evaluate the performance of occupancy models across the WIS with covariates of local faunas and sedimentary rock type for a single season (Campanian) and multiple seasons (early, middle, and late Campanian). Detection probabilities were allowed to vary across lithologies and seasons to model preservational biases. Results showed higher predicted *Hesperornis* occupancy for sites with chondrichthyans, plioplatecarpine mosasaurs, polycotylid plesiosaurs, and offshore shale-forming environments. Increased occupancy estimates with these taxa may reflect a fauna where predation pressures did not significantly affect *Hesperornis* biogeography. Regions of intense study and collection and variable preservation of Campanian outcrops likely inflated the preference for mud-rich offshore environments. This research represents one of the first applications of occupancy modeling to marine vertebrates in the WIS.

53-2 CHANG VAN OORDT, DA*; TAFF, CC; RYAN, TA; VITOUSEK, MN; Cornell University, Ithaca, NY; *dac385@cornell.edu*

Raising Defenses: Are There Costs to Stronger Immunity in Breeding Tree Swallows?

Life history theory predicts that, when resources are limited, energy allocation will be split between somatic and reproductive effort. In order to maximize fitness, organisms should invest these limited resources optimally into either of these efforts via a wide range of traits. This split allocation creates trade-offs when investing in some traits over others such as predator evasion over parental effort, or egg production over immunity. Here, we evaluate the evidence supporting a trade-off between the strength of immunity and life history traits in female Tree Swallows, *Tachycineta bicolor*, from a breeding population in Ithaca, NY. We hypothesize that there should be a trade-off between immunity, the ability to respond to stressors and reproductive effort during demanding life history events such as breeding. Individuals with investment closest to the optimal should have higher lifetime fitness. Bacteria killing assays run using blood plasma, which provide an index of the strength of the innate immune response, revealed wide variation in the response to an *E. coli* challenge. Killing capacity varied from 0 to 100%, with a mean of 47%. Here, we report the relationship between killing capacity and a suite of behavioral (e.g., provisioning rate), physiological (e.g., baseline and stress-induced corticosterone, plasma glucose), and fitness (e.g., clutch size and number of chicks fledged) metrics. We anticipate that this study will provide a better understanding of resource allocation in a migratory bird with a fast pace of life.

51-2 CHAPPELL, DR*; SPEISER, DI; University of South Carolina, Columbia, SC; *danielrc@email.sc.edu*

Neural processing in distributed visual systems – many eyes, many solutions

Most research on visual systems has focused on animals with paired cephalic eyes; however, some animals have distributed visual systems in which many eyes are distributed across their body. Compared to animals with paired cephalic eyes, these animals have nervous systems that are less centralized and less cephalized, which seems at odds with their multitude of eyes and the common notion that vision is an information-rich modality. In most cases it is unknown how these animals process the large amount of information being gathered by their visual systems. To compare neural processing in animals with different distributed visual systems, we studied the bay scallop *A. irradians* and the chiton *A. granulata*. *A. irradians* has dozens of mirror-based eyes, and *A. granulata* has hundreds of eyes embedded in its dorsal shell plates. In both species, we injected fluorescent dyes into eyes to trace the optic nerves to their site of innervation. We found that optic nerves from the eyes of *A. irradians* lead centrally to the parietovisceral ganglion, suggesting central processing of visual information in scallops. In contrast, we found the optic nerves of *A. granulata* lead locally to the lateral nerve cord, suggesting distributed processing of visual information in chitons. Thus, we find two species with distributed visual systems use different strategies for neural processing, with scallops employing centralized processing and chitons employing distributed processing. These different processing strategies may represent underlying differences between nervous systems in which processing occur in ganglia (e.g. scallops and other bivalves) and those in which processing occurs in medullary cords (e.g. chitons and other molluscs).

135-4 CHARIFSON, DM*; BOURDEAU, PE; PADILLA, DK; Stony Brook University, Humboldt State University; *david.charifson@stonybrook.edu*

Shell remodeling may circumvent limits to phenotypic plasticity in the marine gastropod, Nucella lamellosa

The adaptive value of phenotypic plasticity can be limited by several factors, such as the epi-phenotype limit, which is when a newly induced phenotype is not fully integrated with the previous phenotype. Additionally, some inducible morphologies are irreversible, which can result in phenotype-environment mismatch when environmental conditions change. Many marine gastropods thicken their shell in response to shell-crushing predators, an inducible defense, and some are capable of remodeling shell that has already been deposited. However, previous studies of inducible defenses tend to examine only recent shell growth, and not secondary modifications to older parts of the shell (i.e., remodeling). Shell remodeling could allow for reversibility in inducible shell thickening and mitigate epi-phenotype limits. Therefore, we examined plasticity in shell construction and remodeling in *Nucella lamellosa*, which displays a strong inducible shell thickening response to the predatory crab, *Cancer productus*. In response to this predator *N. lamellosa* constructed a thicker shell at the aperture and body whorl, with an increase in both shell microstructural layers at the aperture, but only in one layer in the body whorl. Snails also exhibited shell remodeling in response to *C. productus*; producing an overall thicker shell in older apical whorls. Thus, snails produced the thick or thin shell phenotype throughout all parts of the shell depending on treatment, circumventing the epi-phenotype limit, and suggesting reversible phenotypic plasticity in shell thickness in *N. lamellosa*.

110-4 CHASE, HT*; TOBALSKE, BW; University of Montana; *hilatzipora@gmail.com*

Bird to the Bone: Functional Adaptation in the Avian Wing

Though birds have long been admired by biologists and engineers alike for having lightweight bones with specialized "reinforcements," very little work has been done to investigate this internal substructure (i.e. trabecular bone). Trabecular bone, a complex 3D matrix, mechanically adapts to an organism's behavior over its lifetime. This has facilitated success in using trabecular structure to interpret function in fossil mammals, though no attempt has been made in birds. We thus collected high-resolution microCT scans of the humerus across a broad, comparative set of 51 species which vary in flight mode on a continuum from flapping to soaring. Whole bones were segmented and trabecular matrix parameters were measured for the humeral head. We developed a new parameter (Trabecular Extent, Tb.Ex) to holistically assess the extent of reinforcing structures in the bone. Across corvids, increases in trabecular thickness, ellipsoid factor, and the degree of anisotropy significantly covaried with increases in gliding/soaring behavior, while volume fraction did not vary. Similar patterns were found in a preliminary analysis across the phylogeny. Tb.Ex scaled allometrically within, but not across clades, and also varied with flight mode and ecology. Preliminary comparison of cross-sectional geometry and Tb.Ex suggests a mechanical tradeoff between trabecular and cortical bone. Our results support that trabecular bone in the wing maximizes volume while minimizing mass, but the specific architecture and extent relates to more nuanced differences in kinematics and loading across flight modes and ecologies. Ongoing work will explore the mechanical role of trabecular bone as well as apply our results to fossil interpretation, and overall provides both crucial insight into flight mechanics as well as a robust, novel approach to understanding the evolution of avian flight.

25-5 CHENEY, JA*; SONG, J; WINDSOR, SP; STEVENSON, JPJ; DIERKSHEIDE, D; NILA, A; BOMPHREY, RJ; USHERWOOD, JR; Royal Veterinary College, Hatfield, UK, Royal Veterinary College, Hatfield, UK & Dongguan University of Technology, China, University of Bristol, UK, University of Bristol, UK, LaVision GmbH, Gottingen, Germany, LaVision UK Ltd, Bicester, UK; *jcheney@rvc.ac.uk*

The tails of gliding birds disrupt induced drag minimization and instead approach optimal viscous drag minimization

Textbook descriptions of bird flight discuss the relatively elliptical planform of avian wings as evidence that birds achieve minimum induced drag by enabling constant downwash from tip to tip. To test this description, we measured the wakes of gliding birds by tracking up to 22,000 neutrally buoyant helium-filled soap bubbles at each time point. Our hypothesis was that the action of the tail would compensate for lift lost over the body and enable constant downwash from wingtip to wingtip, minimizing induced drag. Instead, we found that the spread and pitch of the tail produces a strong jet of air that far exceeds the expected downwash; that is, the birds are not elliptically loaded at these slow, self-selected glide speeds. A frequently overlooked action of the tail is to minimize viscid drag, which, in aircraft, is typically a negligible contribution due to higher Reynolds numbers. We found that, at the intermediate Reynolds numbers of avian gliding, the contribution of viscous drag is of the same magnitude as the induced (inviscid) drag. Viscous drag minimization predicts constant area loading, with downwash proportional to chord length at each spanwise position. The measured downwash distribution behind our birds, with a strong downward jet behind the body/tail, is consistent with drag minimization, but reveals a compromise between elliptical loading and constant area loading.

123-5 CHEU, AY*; BERGMANN, PJ; Clark University; *acheu@clarku.edu*

Ontogenetic allometry of locomotor performance in basilisk lizards

For precocious vertebrates, the need for locomotor activity begins soon after hatching or birth. Juveniles may occupy the same habitat as their adult counterparts and therefore, compete for the same resources. Consequently, juveniles must be able to perform multiple locomotor tasks at a reasonably similar level, despite their smaller size. Most animals grow allometrically, where their body proportions change as they get larger. These changes potentially impact their performance in various locomotor tasks. Scaling models have been proposed to predict the relationships between body size and performance variables, where velocity increases with a slope of one, increasing at the same rate as linear body dimensions. While these predictive models do apply in some cases under specific conditions, many empirical studies have shown that the relationship between length and velocity does not always follow the predicted trajectory and slopes may vary between multiple modes of locomotion. Therefore, if a performance variable does not scale as predicted, what are the potential reasons for this deviation? Locomotion can be explained intrinsically by not only the length of body parts, but also cross sectional surface area of muscle fiber types and muscle force generation, all of which scale with different predicted values. This study aims to address (1) if running, jumping, swimming, and climbing performance in brown basilisks, *Basiliscus vittatus*, meet predicted scaling models and (2) which phenotypic traits or kinematic variables best explain potential allometric relationships. Preliminary results show that climbing maximum velocity scales isometrically with body length, but running and swimming velocities scale negatively allometrically. Jumping maximum acceleration has no relationship with body length.

130-6 CHINN, SM*; BEASLEY, JC; University of Georgia; *sarahchinn@uga.edu*

Parental investment strategies in a highly polytocous species: maternal attributes and resource availability modulate litter size and sex ratio

Female condition significantly influences timing of reproduction, age at first breeding and offspring survival, and is proposed as a driver of offspring sex ratio. The Triver's-Willard hypothesis (TWH) predicts high-quality mothers should invest more into sons because males have higher variance in individual fitness for species in which reproductive success is more variable in one sex. Thus, females should adjust offspring sex ratio in response to factors that could modify both their own lifetime reproductive success and that of their progeny. Though well studied in vertebrates, it is poorly understood if or how the TWH applies to polytocous species, those that produce several offspring per litter, because the trade-offs between size and number of offspring must also be taken into consideration. Williams' hypothesis (WH) accounts for these possible trade-offs on sex ratio variation. The extrinsic modification hypothesis (EMH) predicts modulation of offspring sex ratio in response to environmental conditions. Using wild pigs as a model, we tested whether (1) maternal attributes modulated litter sex ratio (TWH), (2) maternal mass influenced production cost, based on litter size and sex-ratio (WM), and (3) environmental conditions influenced litter size (EMH), in a polytocous species. Older females, generally larger and with more parental experience, had male-biased litters, providing support for the TWH. Increased maternal size and condition (an index of resources) both positively influenced litter production cost, supporting the WH and EMH. Increased maternal size and condition also positively influenced litter size but not sex ratio. Our results suggest that for species with large litters, the benefits from adjusting litter size outweigh those from modulating offspring sex ratio.

S11-4 CHITTKA, L; Queen Mary University of London; *l.chittka@qmul.ac.uk*

The Mind of the Bee

Bees have a diverse instinctual repertoire that exceeds in complexity that of most vertebrates. This repertoire allows the social organisation of such feats as the construction of precisely hexagonal honeycombs, an exact climate control system inside their home, the provision of the hive with commodities that must be harvested over a large territory (nectar, pollen, resin, and water), as well as a symbolic communication system that allows them to inform hive members about the location of these commodities. However, the richness of bees' instincts has traditionally been contrasted with the notion that bees' small brains allow little behavioural flexibility and learning behaviour. This view has been entirely overturned in recent years, when it was discovered that bees display abilities such as counting, attention, simple tool use, learning by observation and metacognition (knowing their own knowledge). Thus, some scholars now discuss the possibility of consciousness-like phenomena in the bees. These observations raise the obvious question of how such capacities may be implemented at a neuronal level in the miniature brains of insects. We need to understand the neural circuits, not just the size of brain regions, which underlie these feats. Neural network analyses show that cognitive features found in insects, such as numerosity, attention and categorisation-like processes, may require only very limited neuron numbers. Using computational models of the bees' visual system, we explore whether seemingly advanced cognitive capacities might 'pop out' of the properties of relatively basic neural processes in the insect brain's visual processing area, and their connection with the mushroom bodies, higher order learning centres in the brains of insects.

26-2 CHMURA, HE*; DUNCAN, CM; BARNES, BM; BUCK, CL; CHRISTIAN, HC; LOUDON, AS; WILLIAMS, CT; Institute of Arctic Biology, University of Alaska Fairbanks, Institute of Arctic Biology, University of Alaska Fairbank, Northern Arizona University, Oxford University, University of Manchester; *hchmura@alaska.edu*

Reimagining the hibernating brain: Hypothalamic remodeling in an arctic hibernator

Mammalian hibernation is normally viewed as a state of relative stasis as animals dramatically reduce activity and metabolic rate to weather periods of low resource availability. However, in many species, the end of hibernation involves a transition from fasting to a fed state and is closely followed by seasonal reproduction. These transitions require extensive changes to the brain, physiology, and behavior. This raises the question: does the hibernating brain anticipate this seasonal transition and begin to prepare for spring activity before hibernation ends? We used in-situ hybridization, immunohistochemistry, and electron microscopy to examine neuroendocrine and structural changes in the brains of hibernating male and female arctic ground squirrels. We found significant changes in gene expression across hibernation within the thyroid hormone signaling pathway, including upregulation of TSH- and changes in deiodinases in the mediobasal hypothalamus. Additionally, ependymal tanyctes lining the third ventricle exhibited striking changes; during early hibernation, tanycytic processes were scant within the mediobasal hypothalamus but process density increased late in hibernation. This suggests that the hibernating brain, instead of remaining in stasis, undergoes extensive remodeling. We propose that periodic arousals from torpor, which are typically viewed as functioning in maintaining homeostatic processes, also enable circannual modulation of hypothalamic plasticity.

S5-7 CHO, MS*; NEUBAUER, P; FAHRENSON, C; RECHENBERG, I; Technical University of Berlin, Bionics and Evolution Techniques; *m.cho@campus.tu-berlin.de*

A Filament-like Structure for Flight?: The Ballooning Flight of Spiders

Many flying insects utilize a membranous structure for flight, which is known as a "wing." However, some spiders use silk fibers for their aerial dispersal. It is well known that spiders can disperse over hundreds of kilometers and rise several kilometers above the ground in this way. However, little remains known about the ballooning mechanisms of spiders due to the lack of quantitative data regarding spiders' ballooning. From our observation in the field and the laboratory using a wind tunnel, we acquired knowledge of the types and physical properties of spiders' ballooning silks, previously unknown. A crab spider weighing 20-25 mg spins 50-60 ballooning silks, which are about 200 nm thick and 3.22 m long. Silks of this size can lift large spiders (5-150 mg) into the air even with light upward air currents. In the presentation, the physical signification of these filament-like structures will be discussed in relation to the following questions: (i) Why do spiders use filament-like structures for their flight? (ii) Why do large spiders spin multiple fibers? (iii) Is there any meaning of the thickness of 200 nm?

92-4 CHOI, W*; WADA, H; Auburn University;
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Eggshell Pore Density as an Important Determinant for Avian Embryonic Development
Avian eggs protect embryos from desiccation and trauma while allowing exchange of gases. Although previous studies have shown that environmental factors such as temperature and humidity alter eggshell characteristics, little is known about the importance of those characteristics on embryonic growth and physiology. Here, we assessed how blockage of eggshell pores can affect zebra finch (*Taeniopygia guttata*) embryo hatching success and development pre-hatch. Eggs were divided into four groups: control, fifteen percent, thirty percent, and forty-five percent surface area coverage; the treatment groups were dipped in paraffin candle wax according to their assigned percentages. Eggs were then incubated at 38.6°C, and their heart rates were measured on day 4 and day 10. Hatching success shows a sigmoidal curve where control and 15% coverage have similar hatching success while 30% and 45% having extremely low success. There appears to be a threshold between fifteen and thirty percent where the embryos are able to tolerate this stress.

S8-11 CHOSET, HM; Carnegie Mellon University;
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Geometric Methods for Locomotion in Limbless and Legged Systems
Geometric Methods for Locomotion in Limbless and Legged Locomotion Organisms generate patterns of periodic self-deformations, which we will refer to broadly as "gaits," to locomote through their environments. Inspired by this, the robotics community has created a variety of limbless (e.g., snake) and limbed systems that also use gaits to locomote. Our group has been building upon a branch of mathematics called geometric mechanics that we use to design gaits in mechanical systems, as well as model gaits in biological ones. In this talk, we will show that geometric mechanics facilitates systematic discovery of locomotor templates in diverse living systems, and provides candidate high level control targets for robot control in natural environments. Essentially, our approach establishes a functional relationship, called a connection, that maps changes in the system's internal shape, ie self-deformations, to displacements in position. More specifically, the connection can be used to "map" a closed loop, ie., a gait, in the shape space to displacement. With this technique, we were able to optimize criteria to determine gaits that modeled biological motion. Recently, we have extended the approaches, originally designed for limbless snake-like systems, to multi-legged ones, both biological and robotic. In particular, we are interested in legged systems that also bend their backs, e.g., salamanders, as they have both a "legged" portion and a "undulatory" portion of locomotion.

64-5 CHRISTENSEN , BA*; SCHWANER , MJ; FREYMILLER, GA; CLARK, RW; MCGOWAN, CP; University of Idaho, Moscow , San Diego State University, CA , San Diego State University, CA;
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Exploring Reaction Time in Desert Kangaroo Rats
Desert kangaroo rats (*Dipodomys deserti*) exhibit highly successful escape maneuvers when subject to a predatory attack. Prior studies have loosely attributed the species' success to the unpredictable nature of their evasive response, yet the exact mechanisms remain unknown. Based on literature emphasizing the role of auditory sensitivity in predator-prey dynamics, our goal was to compare kangaroo rat reaction times between auditory and visual cues in the field. For analysis, we used high-speed video cameras (240 fps) to record locomotor response prompted by a rattlesnake strike simulator (RSS). Although the RSS was originally developed to investigate overall escape kinematics, this analysis focused solely on reaction time. Our modified RSS included both auditory and visual triggers, deploying at staggered intervals. For auditory stimulus, we found an average reaction time of 102 ± 6.9 ms (n = 9), slower than past studies have determined. Visual stimulus resulted in an average reaction time of -4.56 ± 6.0 ms, with over half of individuals responding prior to a visual cue. This result indicates the significance of auditory sensitivity over visual sensitivity in kangaroo rat reaction speed. The discrepancy between studies is likely due to design differences as the original RSS required a reliance on visual cues alone and could not quantify auditory involvement. Future analysis will manipulate acoustic frequency to test the lower limits of kangaroo rat hearing threshold, as well as include anatomical data such as auditory bullae size to better explore the links between morphological adaptation and predation pressure.

125-2 CHRISTIANO, BM*; HOWEY, CAF; University of Scranton, University of Scranton and Penn State University;
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Timber rattlesnakes (Crotalus horridus) that move more often maintain higher baseline corticosterone levels
Glucocorticoids are hormones that free up energy which allows organisms to deal with challenging events. Challenging events, or "stressors" can include predictive daily, seasonal, or lifetime changes with regard to the life history of the organism. For example, organisms may maintain elevated glucocorticoid levels during more active times of the year such as foraging or the mating season. The objective of our study was to determine if individual timber rattlesnakes (*Crotalus horridus*) that maintain greater movement rates also maintain elevated baseline corticosterone (CORT) levels. We radio-tracked timber rattlesnakes (n = 12) every 2-3 days for two years (2016 and 2017) and collected blood samples from individuals during mid-summer (reproductive season) of each year. We determined CORT levels for each blood sample using a competitive enzyme immunoassay. We determined movement rates and home range sizes using ArcGIS. We compared individual movement rates with baseline corticosterone levels using a mixed-model linear regression. Individuals with greater movement rates also had higher baseline CORT levels ($F_{1,3}$= 23.76, P = 0.017). Although males tended to have higher baseline CORT levels compared to females ($F_{1,3}$ = 7.95, P = 0.067), it is important to note that not all male snakes had high movement rates (and thus did not maintain elevated baseline CORT levels). Snakes that moved more often maintained larger home ranges (t = 4.48, df = 18,P <0.001). Results from this study can assist biologists in interpreting the effect of behaviors on an animal's physiology and further assist in the definition of a "stressor".

2-4 CHUNG, AK*; COX, RM; LOGAN, ML; MCMILLAN, WO; COX, CL; University of California, Los Angeles, University of Virginia, University of Nevada, Reno, Smithsonian Tropical Research Institute, Georgia Southern University; *akc9ab@g.ucla.edu*
Sex-biased Gene Expression and Sexual Dimorphism in Anole Lizards
Adult males and females of a species often possess differences in body size (sexual size dimorphism, SSD) despite the genomic constraint of a single, shared genome. SSD results from a variety of evolutionary pressures that result in the sexes possessing differing body size optima and represents a form of intersexual conflict. One genetic mechanism that may allow the sexes to overcome the constraint of a shared genome and achieve their body size optima is differential expression of shared genes (i.e. sex-biased gene expression). To understand the role of gene expression in the evolution of SSD, we compared transcriptome expression in a lizard species with extreme male-biased SSD (brown anole) and a species that is sexually monomorphic in body size (Panamanian slender anole). We sampled two tissues that differ in phenotypic expression between the sexes in brown anoles (liver and muscle). We predicted that brown anoles would 1) exhibit high levels of sex-biased expression of the entire transcriptomes of liver and muscle and 2) express growth regulatory networks dimorphically relative to the monomorphic slender anoles. We found that brown anoles do indeed exhibit higher levels of sex-biased expression of both entire transcriptomes and growth regulatory networks in the liver and muscle compared to slender anoles. Ultimately, this work will increase our understanding of the gene expression mechanisms that could resolve intersexual conflict and facilitate the evolution of sexual dimorphisms.

45-6 CHURCHMAN, EKL*; HAIN, TJA; KNAPP, R; NEFF, BD; University of Western Ontario, London, ON, University of Oklahoma, Norman, OK; *echurchm@uwo.ca*
Perceived paternity affects parental care behaviour in bluegill sunfish (Lepomis machrochirus)
Understanding the mechanisms that lead to adaptive behaviour is an exciting interface between levels of analysis in behavioural ecology. Here we manipulated perceived paternity of nest-tending parental male bluegill (*Lepomis macrochirus*) and examined the effect on circulating hormone concentrations and parental care behaviour. Males' perceived paternity was reduced using either an indirect cue of the presence of cuckolder males during spawning, or a direct cue of swapping a portion of the eggs in males' nests. When compared to control males, we found that reduced paternity led to a decrease in males' aggressive behaviour directed towards a brood predator. However, we found no apparent effect of the manipulation on circulating 11-ketotestosterone concentrations. We will discuss the effect of prolactin with the goal of understanding the mechanisms influencing adaptive parental care decisions.

28-3 CIERI, RL*; FARMER, CG; University of Utah; *bob.cieri@gmail.com*
Net-unidirectional airflow patterns vary with pulmonary anatomy in monitor lizards (Varanidae): insights from a multi-species computational fluid dynamics investigation
Varanids are a remarkable group of lizards that exhibit great variation in body mass, ecological niche, and aerobic capacity but retain a conserved body plan. Their lungs also vary and are an ideal group in which to investigate the functional and ecological significance of pulmonary traits. Our group reported unidirectional flow in the larger chambers of *Varanus exanthematicus* but detailed flow patterns and how these patterns vary among species remains unknown. Studying airflow in varanid lungs is difficult because much of the lung is dense parenchyma that cannot be accessed with flow probes. Computational fluid dynamics (CFD) can overcome these difficulties by generating simulations of pulmonary airflow based on computed tomography (CT) data that can be validated on real lungs. Airways were segmented and made into surface files in Avizo. Surface models were meshed into a computational meshes using the unstructured mesh generation utility, snappyHexMesh. CFD simulations were run using a custom PIMPLE-based dynamic solver in OpenFOAM. Varanid lungs consist of an intrapulmonary bronchus (IPB) that ends in a caudal bronchus, branches cranially into a hilar-cranial bronchus (HCB), and opens throughout into secondary bronchi that interconnect via perforations. Smaller species have fewer but larger caudal chambers and relatively thicker IPBs. Flow in *V. exanthematicus* is net-unidirectional: the IPB moves air net caudally, the secondary bronchi move air net cranially, and the HCB is tidal. In *V. spenceri*, which has a has a thin IPB, the dorsal aspects of secondary chambers carry net caudal flow and the ventral aspects carry net cranial flow. These results show that pulmonary airflow patterns in varanids vary with life-history traits and varanid lungs contain a mix of unidirectional and tidal lung traits.

130-1 CIRINO, LA*; LENGA, SH; MILLER, CW; University of Florida; *lacirino@ufl.edu*
Males with damaged weapons produce more offspring in non-competitive environments
Some males engage in fierce competitions using elaborate weapons to gain access to females and reproduction. Yet, not all males in these species have large or robust weapons. Weapons can become damaged and this phenomenon is surprisingly common. When weapons are compromised, males are less likely to win male-male competitions or may avoid them altogether. Thus, males in species that use weapons to secure females are likely to have evolved alternative routes to achieve reproductive success. One way may be to boost sperm production, so males can provide more ejaculate to females in the rare cases that they are encountered. In this study, we examined whether males with weapons damaged during development have increased offspring production. We induced developmental hind leg weapon damage in *Narnia femorata* (Hemiptera: Coreidae), a species that exhibits resource defense polygyny and is known to increase testes size when a weapon is lost during development. We then mated intact and weapon damaged males with four virgin females successively. Weapon damaged males produced more offspring with large females. We also noted behavioral differences between male groups. Large males with intact weapons mated with more females than weapon damaged males. Together, these results suggest that damaged males have a larger ejaculate and may be strategically investing that ejaculate in fewer females, leading to the increase in overall reproductive success. When weapon damage limits male access to females, they are able to employ an alternative reproductive strategy to counteract their diminished opportunities to mate. This strategy may help maintain variation in a population and relax the strength of sexual selection on these weapons.

S6-1 CLARK, CJ; University of California, Riverside; *cclark@ucr.edu*
Introduction to the Symposium on Bioinspiration of silent flight of owls and other flying animals
Owls are well known for their nearly soundless flight, in comparison to the wing sounds of other birds. Owls have evolved wing and tail features, including a comb-like structure on the leading edge of the wing, a 'velvet' in between adjacent wing feathers and tail feathers, and fringed feather margins that are associated with sound reduction. Recent studies have used techniques such as beamforming and computational fluid dynamics models to understand how these wing structures suppress sound in flight. The stated intent of these studies is to discover whether any evolved features of owl wings may have a design basis with technological application to noisy human devices such as drones, windmills or trains. Neurobiologists have extensively studied owl hearing as a model for sound localization. The purpose of this symposium is to bring together biologists and engineers to discuss ongoing research in 'animal aeroacoustics', the study of how animal flight produces an acoustic signature, and its biological context.

S6-9 CLARK, CJ*; LE PIANE, K; CLARK, Christopher; University of California, Riverside; *CCLARK@UCR.EDU*
Evolutionary and ecological correlates of silent flight in owls, nightbirds and hawks: Does silent flight evolve for stealth, or to reduce self-masking?
Owls, Nightbirds (nocturnal members of Caprimulgiformes) and certain hawks have all evolved feather features that reduce the sound they produce in flight. These features are: a leading edge comb (owls) which reduces sound primarily below 10 kHz; vane fringes (owls and nightbirds), which may reduce low or high-frequency sound; and a velvet on the dorsal surface of their wing and tail feathers (all three groups) which ameliorates broadband rubbing sound that includes substantial ultrasound (sound as high as 50 kHz). Two non-mutually exclusive hypotheses make predictions about why silent flight has evolved. The self-masking ("owl ear") hypothesis states that wing sounds reduce the predator's ability to hear prey sounds, thus silent flight enables the predator to better locate prey. The stealth ("mouse ear") hypothesis states that wing sounds reduce the ability of prey to hear the predator approach, limiting the prey's ability to take evasive action in response to an attack. For owls, which hunt by ear, most available lines of evidence better support the self-masking hypothesis, such as: increases in background sound reduce owl hunting success. For nightbirds, the data better support the stealth hypothesis, as nightbirds do not use sound to hunt and their wing features reduce ultrasound not audible to them but audible to their insect prey. For hawks the answer is unclear; while all hawks use visual cues to hunt, some hawks also use acoustic cues, and not enough is known about either the use of sound nor the distribution of silencing features within Accipitriformes to draw firm conclusions about their function.

32-3 CLARK, RM*; FOX, TP; HARRISON, JF; FEWELL, JH; Siena College, Loudonville, NY, Arizona State University, Tempe, AZ; *rclark@siena.edu*
Energetic Savings of Grouping During Nest Initiation in Harvester Ants
Queens of the seed-harvester ant *Pogonomyrmex californicus* vary geographically in their propensity to cooperate with each other when starting a new colony, leading to questions about the mechanisms that facilitate such grouping and cooperation. Given recent studies that show that ant colony mass-specific metabolic costs decline with group size, we tested the hypothesis that cooperation provides a metabolic advantage for queen pairs during colony founding. We determined that the most energetically intense period of nest initiation extends from the postmating period, through nest excavation, until the onset of brood-rearing. Correspondingly, both queens with an evolutionary history of cooperative nest-founding and queens that lack this history showed reduced mass-specific metabolic rates when paired together during the most energetically intense period. This effect occurred independently of any metabolic costs associated with locomotion. Collectively, our findings suggest that the simple act of grouping somehow provides a direct energetic benefit to queens during the energetically demanding life stage of colony founding, regardless of whether or not queens have actually evolved to cooperate during this period. This research was partially supported by NSF IOS 1558127.

S6-12 CLARK, CJ; CLARK, Christopher; UC Riverside; *cclark@ucr.edu*
Final roundtable discussion on bioinspiration of silent flight
We conclude our symposium on bio-inspiration of silent flight of owls and other flying animals, by discussing open questions within this area, with an eye towards identifying areas of research that are not currently being addressed. Open engineering questions include: what is the role of wing flapping in the acoustics of bird flight? Does flapping fundamentally alter the airflow over a wing (such as through the leading edge comb of an owl's wing), and its acoustic signature? On the biological side: What types of sound are owls and other silent flyers selected to reduce? What is the relationship between the adaptations to reduce flights sounds, and the hearing of the predator and prey? The final goal of this discussion is to explore bio-inspiration of silent flight. What types of biological data are most important for inspiring new directions of ‘bio-inspiration'? And what are the potential engineering applications of discoveries that may yet be made on how animals make sound as they fly?

78-2 CLAVEL, J*; MORLON, H; The Natural History Museum, École Normale Supérieure; *j.clavel@nhm.ac.uk*

Phylogenetic Signal and Linear Model for High-Dimensional Multivariate Comparative Data: a case study with the MANOVA

Phylogenetic linear models (e.g., regressions, ANOVA, or ANCOVA) provide a statistically rigorous framework for comparative studies of phenotypic traits across taxa. However, the development of their multivariate counterparts is still lagging behind because of the computational challenges encountered with multidimensional datasets. In particular, when the number of traits *p* approach or exceed the number of taxa *n*, the conventional statistical machinery is limited, and we have to rely on alternative methods that are approximate and restricted to the Brownian motion model of trait evolution. Here we developed more flexible multivariate phylogenetic linear models (e.g., multivariate regressions, MANOVA, MANCOVA) to deal with the high-dimensionality of modern high-throughput comparative datasets. We used intensive simulations to assess the performances of the proposed approaches to various level of phylogenetic signal, of correlations between the traits, and distributions of phenotypic changes in the multivariate space. We show that the proposed approaches outperform conventional ones when *p*, and current alternative when *p>n*. We further show that current available approaches to deal with high-dimensional datasets lack the power to detects differences in multivariate datasets and may have high type I error rates. Finally, we provide an empirical test of our phylogenetic MANOVA on a geometric-morphometric dataset describing the mandible morphology in phyllostomid bats along with data on their diet preferences. Overall our results show significant differences between ecological groups while accounting for the mild phylogenetic signal of these ecomorphological data. We provide some guidance on the use of multivariate statistics for comparative analysis and discuss some recent concerns about the use of phylogenetic comparative methods.

18-2 CLEMENTS, KN*; HEAGY, FK; BLAIN, E; WARD, J; ISSA, FA; East Carolina University, Greenville, NC; *clementsk10@students.ecu.edu*

Repeated Social Defeat Affects Dopaminergic Modulation of Spinal Motor Circuits

Social submission negatively impacts behavior and physiology of many social animals, yet the effects of repeated social defeat (RSD) on nervous system function underlying locomotion remain poorly understood. We investigated how RSD affects dopaminergic modulation of swimming and startle escape in zebrafish. Paired zebrafish form dominance relationships where subordinates are repeatedly defeated by their opponents. We showed that subordinates swim less and increase startle escape compared to dominants. Dopamine (DA) is involved in regulating locomotion by directly modulating spinal circuits. We studied whether DA signaling underlies this shift in locomotor activity. Western blot results showed that RSD decreases expression of dopamine 1 receptor (D1R). Pharmacological blockage of D1R caused dominants to swim less and escape more, resembling subordinate behavior. We also tested these behaviors in D1R knockout fish and found that they exhibited subordinate-like locomotive patterns. This suggests that RSD affects DA modulation of motor circuits by regulating the expression of D1R on postsynaptic targets. To test whether RSD also induces morphological changes within the presynaptic DA system, we counted the number of DA neurons in the hypothalamic A11 DA nuclei with Tg(dat:EGFP) zebrafish. The A11 nucleus is known to project into the spinal cord and modulate swim and escape circuits. Preliminary results of confocal images showed that RSD decreases total number of DA neurons in the A11. This suggests A11 is influenced by chronic defeat and allows exploration of if these neurons modulate the escape and swim circuits in the context of RSD. Our results highlight how RSD impacts CNS function and how this modifies adaptive motor behavior.

135-2 CLIFTON, IT*; CHAMBERLAIN, JD; GIFFORD, ME; University of Toledo, Southern Arkansas University, University of Central Arkansas; *Ian.Clifton@rockets.utoledo.edu*

The Role of Phenotypic Plasticity in Morphological Differentiation Between Watersnake Populations

An individual's morphology is shaped by the environmental pressures it experiences, and the resulting morphological response is the culmination of both genetic factors and environmental (non-genetic) conditions experienced early in its life (i.e., phenotypic plasticity). The role phenotypic plasticity plays in shaping phenotypes is important, but evidence for its influence is often mixed. We exposed female neonate diamond-backed watersnakes (*Nerodia rhombifer*) from populations experiencing different prey-size regimes to different feeding treatments to test the influence of phenotypic plasticity in shaping trophic morphology. We found that snakes in a large-prey treatment from a population frequently encountering large prey exhibited a higher growth rate in body size (SVL) and in head length than individuals in a small-prey treatment from the same population. This pattern was not observed in snakes from a population that regularly encounters small prey. We also found that regardless of treatment, snakes from the small-prey population were smaller at birth than snakes from the large-prey population and remained so throughout the study. These results suggest that the ability to plastically respond to environmental pressures may be population-specific. These results also indicate a genetic predisposition towards larger body sizes in a population where large prey items are more common.

139-1 CLIFTON, GT*; HOLWAY, D; GRAVISH, N; Univ. of California, San Diego, UCSD; *glclifton@eng.ucsd.edu*

The influence of uneven terrain and vision on ant walking

Visual feedback substantially informs vertebrate walking coordination and control, but the ability of some ant species to forage at night and through dark tunnels suggests that vision may be less essential for certain insects. To understand how vision influences walking performance under naturally rugged conditions, we recorded 3900 high-speed videos of Argentine ants (*Linepithema humile*) walking on 3D-printed substrates both in light and dark conditions. Ants walking on flat ground showed a small, but significant shift to slower speeds in the dark. On a checkerboard substrate, ants walked 50% slower but, surprisingly, lighting did not influence speed. Pathway sinuosity increased on the checkerboard array but did not change between light and dark conditions. Since many walking perturbation studies focus on a discrete step, we also included a step substrate. When confronted with a step up, ants decelerated on average ~2.8 mm before the step, a distance corresponding to when the antennae first contact the step. For stepping down, ants slowed down <1 mm from the step approximately when the forelimbs would reach the step edge, regaining original speeds only 2.5-3 mm after the step. Together these findings support that vision does not critically impact walking for the Argentine ant, especially on uneven terrain. Instead, ants could either walk without sensory feedback or by relying on tactile and proprioceptive cues from the antennae and limbs. The reduced influence of vision in this ant species could stem from slow visual perception relative to movement speeds and from the ability to generate large body accelerations using specialized tarsal structures. These results have the potential to inform insect neuromechanics, inspire new robotic control strategies, and explain ecological patterns in life history.

48-5 COELHO, JC*; POOLE, AZ; Berry College, Berry College ; *Jenny.Coelho@vikings.berry.edu*

The Evolution and Role of GTPases of Immunity Associated Proteins (GIMAPs) in Cnidarians

Corals, which are members of Phylum Cnidaria, play a critical role in coral reefs, one of the world's most productive and diverse ecosystems. Coral reef health depends on a mutualistic symbiotic relationship between cnidarians and photosynthetic dinoflagellates of the family Symbiodiniaceae. However, a variety of stressors to reefs such as elevated temperatures and coral disease contribute to breakdown of this symbiotic relationship which can lead to coral death and collapse of the reef ecosystem. To better understand coral disease and symbiosis, we looked at a group of potential immune proteins in cnidarians called GTPases of immunity associated proteins (GIMAPs). In vertebrates these proteins regulate the fate of developing lymphocytes and a previous study revealed their presence and potential immune function in cnidarians. To better understand the evolution of GIMAPs within this phylum, bioinformatic searches were conducted in a diversity of publicly available genomes and transcriptomes. Additionally, to better understand the role of GIMAPs in cnidarian immunity and symbiosis, both symbiotic and aposymbiotic *Exaiptasia pallida* were exposed to the immune stimulant lipopolysaccharide (LPS) and gene expression of four GIMAP-like sequences called *Ep_GIMAPs* was measured using qPCR. The bioinformatic searches revealed two types of GIMAP-like sequences termed long and short, with patchy distribution, including cnidarians that contain one, both, or neither GIMAP type. The gene expression work showed two of the *Ep_GIMAPs* had greater expression in symbiotic than aposymbiotic *E. pallida*, implying a function in regulating symbiosis. However, *Ep_GIMAPs* did not show significant expression differences in response to LPS treatment, suggesting a role other than immunity. Overall, this work provides a greater understanding of the cnidarian immune system and the evolution of GIMAPs.

54-3 COFFIN, JL*; KELLEY, JL; TOBLER, M; Kansas State University, Washington State University; *jlcoffin3@gmail.com*

Adaptation to Life in Acid Mine Drainage: Transcriptomics and Molecular Evolution in Western Mosquitofish

The world has seen an unprecedented increase in anthropogenic inputs of numerous elements since the onset of the industrial revolution, often leading to perturbed or destroyed ecosystems. Heavy metals sourced from the byproducts of mining activities are common contaminants in the biosphere and can have detrimental effects at all levels of biological organization. The Tri-State Mining District of Kansas, Missouri, and Oklahoma has long been characterized by elevated heavy metal concentrations in animals and humans from improper waste management, leading to the designation of the Tar Creek Superfund Site. The surviving ichthyofaunal community of Tar Creek is dominated by Western mosquitofish (*Gambusia affinis*), which also inhabit neighboring, unpolluted watersheds, facilitating comparative analyses of physiological and evolutionary responses to heavy metal pollution. We coupled molecular evolutionary analyses in related fishes inhabiting extreme environments with RNA-sequencing of gill, liver, and brain tissues of *G. affinis* to address basic questions regarding evolutionary responses to heavy metal stress: 1) which genes are experiencing positive selection in populations of *G. affinis* inhabiting polluted habitats?, and 2) what genes are differentially expressed between populations of *G. affinis*? We hypothesized that genes involved with metal homeostasis would be under positive selection and be upregulated in the Tar Creek population of *G. affinis*. These analyses will allow us to investigate how heavy metal pollution might impact rapid evolutionary responses and understand the mechanisms that have allowed *G. affinis* to inhabit heavy metal contaminated extreme environments.

129-1 COHEN, HE*; KANE, EA; Georgia Southern University; *hc02684@georgiasouthern.edu*

When the Expected Doesn't Happen: A Lack of Local Adaptation in Trinidadian Guppies

When populations occupy different environments, divergent selection pressures can result in phenotypic differentiation in traits that provide a local fitness advantage. Trinidadian guppy (*Poecilia reticulata*) populations are separated by physical barriers which result in repeated shifts in selective pressures from predator avoidance in high predation environments towards resource competition in low predation environments. Previous studies have shown that these changes result in a range of locally adapted morphological and behavioral traits, including color, length of gestation, and shoaling behavior. Regarding prey capture, although consumption rates and head morphology may differ, suction-feeding behaviors do not, and the role of local adaptation on feeding is unclear. We analyzed morphological differences such as body size, eye area, jaw positioning and body depth to validate known differences between populations. Since biting is a more relevant behavior for guppies, we then filmed adult females from replicate high/low predation pairs while they used biting behaviors to feed on an agar substrate. We did not find divergence in either morphological or kinematic traits, suggesting a general lack of local adaptation, contrary to previous findings. A lack of divergence could be due to less pronounced morphological divergence in females, perhaps as a constraint of bearing young, and the absence of divergent selection on prey capture performance. In female guppies, morphology and performance are not locally adapted, and divergence may exist primarily in behavioral traits (consumption rates) as a result of competition in low predation environments.

S3-3 COHEN, K.E*; WELLER, H.I; SUMMERS, A.P; University of Washington , Brown University , University of Washington; *kecohen@uw.edu*

What is homodonty?

Homodonty and heterodonty attempt to capture tooth battery morphology as it relates to prey processing. Homodont teeth are similar in shape or size and assumed to perform a uniform task. Heterodont teeth have shape regionalization and are associated with regionalized functions. These categories have poorly defined boundaries: how much morphological variation is permitted in a homodont dentition before it should be classified as heterodont? Development, replacement, and damage directly alter the shape and size of teeth along the jaw further complicating homodonty. Incipient, transient, or phylogenetic homodonty attempt to provide a more rigorous definition by incorporating additional contingencies, but instead serve to highlight the difficulties in categorizing dentitions. For instance, conical teeth are a simple shape with a simple job of puncture. Yet they vary in length, curvature, and sharpness as a result of additional selective pressures aside from puncture. By constraining homodonty to static shape, we miss aspects of how teeth are being used. Instead we propose to use function to tease apart not just how teeth look, but how they are used. We present a functional lens on homodonty by looking at stress, orientation, and curvature. These functional parameters allow us to analyse how large and small teeth work together to transmit forces to a prey item. Our results show that the placement of teeth affects their function and that there is a functional advantage to having several smaller teeth surrounding a singular large tooth. Our statistical models present a new tool for determining ‘functional homodonty' and a series of dentitions that demonstrate the complexities of this problem. We show that teeth that look alike don't always act alike; morphologically heterodont teeth are functionally homodont.

35-7 COLOMBERO, CR*; WAINWRIGHT, DK; LAUDER, GV; Harvard University, Yale University; *crcolombero@college.harvard.edu*

Shark Dermal Denticles: Loss and Regeneration Patterns Vary with Body Position and Ecotype

Dermal denticles – the characteristic scale-type of sharks – are tooth-like structures embedded in the skin. Observation of denticles in a diversity of shark species and body locations reveals "gaps" in the denticle surface pattern where denticles are missing. These missing denticles may be lost as a result of natural replacement cycles or through injury, although little is known about the extent of these gaps in the shark skin surface and how (or if) denticles are replaced. In order to quantify the extent of missing denticles and describe the pattern of denticle replacement, we used four imaging techniques: (1) High-resolution μCT scanning to generate volumetric models, (2) surface profilometry to scan the surface for missing denticles, (3) Scanning Electron Microscopy (SEM), and (4) histology for visualization beneath the skin surface. The percent surface area of missing denticles was calculated for 10 shark species with benthic, coastal mid-water, and pelagic ecologies, and we observed replacement denticles forming and emerging from the dermis and epidermis in the gap regions. Our findings indicate that dermal denticles replace themselves and that this process begins after a scale has been lost. Replacement denticles develop crown-first and are weakly ossified early-on, with a large open pulp cavity and lacking a true root. Thus far, the tails of highly pelagic species including the thresher and mako sharks (*Alopias vulpinus* and *Isurus oxyrinchus*, respectively) have the highest percentage of missing denticles of the species surveyed, although even benthic sharks show gaps in the denticle surface and generation of emerging replacement denticles.

111-4 COMBES, SA*; GAGLIARDI, SF; WARGIN, AH; U.C. Davis; *sacombes@ucdavis.edu*

Wing damage isn't all bad for bumblebees: Asymmetric damage impairs maneuverability, but symmetric damage improves stability

Bumblebees fly through cluttered environments while foraging for resources, and collisions with vegetation cause irreversible wing damage that accumulates with age. Wing damage has been linked to increased mortality in bees, but the mechanism behind this finding remains unclear. We examined the effects of wing damage on two major aspects of flight performance, stability and maneuverability. We filmed 25 *Bombus impatiens* flying with a 2.5 m/s headwind in three conditions: in unsteady, structured flow generated by an upstream cylinder, while maneuvering to track a laterally oscillating flower, and while maneuvering to track a flower in the presence of unsteady flow. Bees flew in all three conditions with intact wings, with asymmetric damage (~20% area clipped from one wing), and with symmetric damage (~20% area clipped from both wings). To quantify stability and maneuverability, we calculated translational and rotational body orientation, and evaluated flower tracking performance. Neither type of damage led to significant changes in stability during flight in unsteady flow, but maneuverability during tracking was reduced by asymmetric (but not symmetric) wing damage. When unsteady flow was combined with the challenge of tracking a flower, we did find an effect of wing damage on stability; however, in this case symmetric wing damage actually improved stability over intact wings, whereas asymmetric damage had no effect. These results suggest that reduced maneuverability caused by natural wing damage, which is typically asymmetric, could underlie the increased mortality found in previous studies. However, bees' overall flight performance is impressively robust to wing damage, and symmetric damage can even provide stability benefits that may help compensate for the loss of force-producing wing area.

118-5 CONITH, AJ*; HOPE, S; LIU, M; ALBERTSON, RC; UMass Amherst; *ajconith@bio.umass.edu*

The Developmental and Functional Origins of a Key Feeding Innovation in the Cichlid Pharyngeal Jaw

The perciform group Labroidei (cichlids, labrids, damselfish, and surfperches), have independently evolved pharyngognathy, a highly derived set of upper and lower pharyngeal jaws (U-LPJ). The muscle that retracts the UPJ, the retractor dorsalis (RD), connects the UPJ to the anterior vertebrae and functions to process prey. Cichlids are unique in having developed a ventrally projected pair of processes at the posterior connection between the RD and vertebrae, typically on the third vertebrae. It is not uncommon to find these projections shifted anteriorly, which shortens the RD muscle and has consequences for UPJ performance. Here we characterize the shape and development of the vertebral projections using morphometric and genetic methods. We sought to answer two questions: 1, how functionally integrated is the UPJ musculoskeletal system, and 2, can we take a candidate gene approach to find regions of the genome responsible for vertebral projection development? We μCT scanned 640 individuals from a hybrid cross between two Malawi cichlids and used 3D morphometrics to characterize neurocranium and vertebral shape. We then extracted shape scores from our vertebral data, which reflected projection positioning, and performed quantitative trait loci (QTL) mapping. We found a strong association between the vertebral and neurocranium shapes, suggesting an anterior shift of the projections produces a change to the mechanics of UPJ retraction. We also gain two significant QTL peaks in our map, which reveal a possible role for the SIK pathway in regulating the development of these projections. Taken together, this suggests a small developmental change in the pathway regulating projection positioning can produce large-scale changes the mechanics of UPJ performance.

48-1 CONKLING, ME*; HESP, K; MUNROE, S; SANDOVAL, K; MARTENS, DE; SIPKEMA, D; WIJFFELS, RH; POMPONI, SA; Florida Atlantic University, Fort Pierce, FL, Wageningen University, Wageningen, NL; *mconkli2@fau.edu*

Breakthrough in Marine Invertebrate Cell Culture: Sponge Cells Divide Rapidly in Improved Nutrient Medium

Sponges (Phylum Porifera) are among the oldest Metazoa and considered critical to understanding animal evolution and development. They are also the most prolific marine source of chemicals with pharmaceutical relevance. Cell lines are important tools for research in many disciplines, and have been established for many organisms, including freshwater and terrestrial invertebrates. Despite many efforts over multiple decades, there are still no cell lines for marine invertebrates. In this study, we report a breakthrough: we demonstrate that an amino acid-optimized nutrient medium stimulates rapid cell division in 9 sponge species. The fastest dividing cells doubled in less than 1 hour. Cultures of 3 species were subcultured from 3 to 5 times, with an average of 5.99 population doublings after subculturing, and a lifespan from 21 to 35 days. Our results form the basis for developing marine invertebrate cell models to better understand early animal evolution, determine the role of secondary metabolites and predict the impact of climate change to coral reef community ecology. Furthermore, sponge cell lines can be used to scale-up production of sponge-derived chemicals for clinical trials and develop new drugs to combat cancer and other diseases.

101-2 CONRAD, H*; WITTMAN, T; POLLOCK, N; JOHN-ALDER, H; Rutgers University, University of Texas, University of Virginia; *hmc87@scarletmail.rutgers.edu*

Tolerance of ectoparasitism in Eastern Fence Lizards, Sceloporus undulatus

Eastern fence lizards (*Sceloporus undulatus*) are heavily parasitized by chigger mites (*Eutrombicula alfreddugesi*), with mite counts >500 on some individuals. Among growing yearlings, mite counts vary by an order of magnitude, and the week-to-week rank ordering of mite counts is highly concordant. In yearlings, males are more heavily parasitized than females, even as mite populations change across the summer activity season. Thus, any potential costs of ectoparasitism may vary consistently among individuals and between males and females. Furthermore, exposure of lizards to mites may be increasing with climate change, potentially leading to higher ecological costs. We investigated growth costs of chigger mites in field-active yearling *S. undulatus* in three independent studies conducted in 2014-15, 2016, and 2019, and we attempted to manipulate ectoparasitism experimentally by administering Ivermectin in 2019. We found no evidence of a negative correlation between mite count and growth rate in either sex. Furthermore, Ivermectin had no effect on mite counts or growth rates. Yearling males had consistently lower growth rates than females, consistent with findings that testosterone inhibits growth in *S. undulatus*, but the inhibitory effect of testosterone on growth in males does not appear to be mediated through increased mite parasitism. Average mite intensities increased progressively across years, suggesting that exposure to mites may be increasing as the climate warms. Given these conditions, selection may favor the evolution of tolerance as opposed to resistance to mites. If so, further increases in mite populations due to climate change may have little effect on *S. undulatus*. Supported by NSF 1754934 and Hatch Multistate project no. NJ17240.

116-6 CONVERSE, A*; THOMAS, P; University of Texas Marine Science Institute; *aubreykoch@utexas.edu*

Female ZIP9-Knockout Zebrafish Exhibit Abnormal Egg Activation and Reduced Fecundity

Our research group recently cloned and characterized a putative membrane androgen receptor from teleost ovarian tissue that is homologous to the zinc transporter protein ZIP9 (Slc39a9). Since the discovery of its androgen receptor activity, ZIP9 has been found to mediate androgen actions in a number of cell culture models from various tissues. However, ZIP9 has not been examined in an *in vivo* model so the precise physiological functions of this receptor remain unclear. A ZIP9-mutant strain of zebrafish was developed using a CRISPR-Cas9 system to examine the role of the protein in teleost reproduction. Mutant females have reduced fecundity and spawn significantly fewer eggs than wild-type fish. ZIP9-mutant females also produce a high proportion of eggs that do not undergo chorion elevation, a characteristic of normal egg activation. Eggs that show this phenotype have low fertilization rates and produce larvae that exhibit a high incidence of pericardial/yolk sac edema and reduced growth compared to larvae hatched from wild-type eggs. Zinc detection using fluorescent probes indicated that in wild-type eggs, zinc is localized to intracellular vesicles prior to activation, but once activation occurs the number of zinc containing vesicles decreases and a rise in extracellular zinc is detected. This suggests that zinc is released during activation in fish eggs similar to observed in mammalian eggs. ZIP9-mutant eggs that show the abnormal activation phenotype also show abnormal zinc vesicle morphology in that the vesicles are significantly smaller than those of wild-type eggs. Thus, the potential disruption of zinc regulation during egg activation and/or maturation in ZIP9-mutant fish may account for the abnormal activation phenotype and the reduction in viable offspring produced by mutant fish.

138-1 COOMES, CM*; DERRYBERRY, EP; University of Tennessee Knoxville; *cmcoomes@gmail.com*

It's too darn hot: Effects of ambient temperature on singing behavior in male song birds

Due increasing heat waves, animals are facing more challenges induced by increasing temperatures. Birds are particularly vulnerable to high temperatures as they are diurnal and have limited access to cooler microclimates. Exposure to high temperatures has been shown lead to changes in critical behaviors. For example, song birds have been shown to sing less when temperatures are higher. Song is crucial for communicating territory boundaries and advertising mate quality. Here, we experimentally tested how temperatures affect song production in male zebra finches. We used a repeated measures design and recorded all songs produced in three temperature treatments: 27°C, 35°C, and °C, or below, within, and above the zebra finch thermal neutral zone (TNZ) respectively. We found that song production was highest at temperatures within the TNZ and was lowest above the TNZ. We discuss our results in terms of the effects of high temperatures on wild birds, as zebra finches experience heatwaves in the wild. These results may also inform future experiments, as zebra finches are often tested at room temperature, which is below the zebra finch TNZ, where we show potential effects on song production.

66-1 COOPER, C*; KEELING, E; LIWANAG, H; California Polytechnic State University; *Ccoope05@calpoly.edu*

Feeling out your Food: A histological analysis of the vibrissal system in pinnipeds

The vibrissal (whisker) system is present in nearly all mammals and is especially important in deep-diving mammals. Pinnipeds (seals, sea lions, walrus) have highly innervated whiskers, indicating they serve as important sensory structures. Vibrissae are needed for foraging and thus it is vital to maintain their functionality under all environmental conditions. In pinnipeds studied thus far, each vibrissal unit includes a follicle sinus complex characterized by a three-part blood sinus system: the upper cavernous sinus (UCS), ring sinus (RS), and lower cavernous sinus (LCS). The UCS is unique to pinnipeds and lacks innervation. Based on this, we hypothesize that the UCS plays a thermoregulatory role, insulating temperature-dependent mechanoreceptors. Our objectives were (1) to measure and compare the relative lengths of the three sinuses (UCS, RS, and LCS) among three pinniped species and (2) to examine the UCS as a thermoregulatory structure. To do this, we measured and compared the relative lengths of the UCS in deep-diving polar Weddell seals (*Leptonychotes weddellii*, n=6), deep-diving temperate northern elephant seals (*Mirounga angustirostris*, n=4) , and shallow-diving temperate harbor seals (*Phoca vitulina*, n=2). Individual vibrissal follicles were collected and histologically processed from animals that died in the wild or during rehabilitation efforts. We predicted that the species faced with the coldest environment both at depth and in air (i.e., Weddell seals) would have the longest UCS. Our preliminary results suggest a positive correlation between the total sinus length and the average UCS length. This represents the first study to characterize the microstructures of the vibrissal system in Weddell seals and the first study to investigate the UCS as a thermoregulatory structure.

75-2 COOPER, AN*; MARTIN, JC; MCDERMOTT, WJ; DULANEY, SO; CARRIER, DR; University of Utah, The Orthopedic Specialty Hospital, Murray, UT; *amanda.cooper@utah.edu*

The Role of Muscle Fascicle Length in the Power versus Economy Performance Trade-off

The ability of the locomotor muscles to effect both economical transport and powerful bursts of activity is necessary for survival in many species. However, specialization in either of these performance traits is expected to negatively impact the other due to functional constraints in muscle design, resulting in a performance trade-off. The muscular power *versus* economy trade-off has traditionally been explained by muscle fiber type composition. Although fiber type plays an undeniable role in performance specialization, differences in muscle architecture may also determine the economy and power of a muscle. Muscles with longer fascicles, composed of more in-series sarcomeres, are capable of faster shortening velocity, allowing for increased power production. However, long fascicles are expected to reduce economy because, for a given force production, more energy-consuming contractile units must be activated. We hypothesized that longer muscle fascicle length is positively correlated with both power production and increased locomotor cost. In a set of 11 power- and 13 endurance-trained athletes, we measured 1) gastrocnemius lateralis (GL), gastrocnemius medialis (GM), and vastus lateralis (VL) muscle fascicle length via ultrasound, 2) maximal power production during cycling and countermovement jumps, and 3) running cost of transport. We found that longer fascicles in GL and GM are positively correlated with both cycling and jumping power, and that longer GL fascicle length is directly correlated with increased cost of transport. These results are consistent with the hypothesis that, at least for certain muscles, fascicle length plays a significant role in the performance trade-off between power and economy.

137-2 CORBIN, CE*; ROPER, VG; Bloomsburg University; *ccorbin@bloomu.edu*

Linking Effects of Acid Mine Drainage to Ecology and Morphology of Riparian Birds

Acid mine drainage (AMD) constrains within-stream trophic linkages and has negative effects on freshwater ecosystems. The extent to which AMD affects higher trophic levels in riparian ecosystems is not well known. Additionally, it is unknown how AMD affects the ecomorphological relationships between stream and riparian ecosystems. Some terrestrial organisms that normally acquire nutrients from stream may either avoid or be excluded from polluted areas. If true, then AMD potentially constrains cross-ecosystem energy transfer, and may influence the emergent properties of biological organization such as population densities, community membership, and functional ecomorphological relationships. Our goals were to 1) explore the similarities and differences between AMD and non-AMD bird community membership, 2) test for numerical responses in aerial insectivores along those tributaries and 3) determine if there is a morphological, and hence functional loss these AMD affected streams. We conducted bird and nest surveys along tributaries of the Susquehanna River with varying degrees of AMD pollution. We characterized and compared the morphological space of bird communities of AMD and non-AMD streams. Analysis of variance, Monte-Carlo null-community analysis, and non-parametric statistical tests indicate there are fewer species, particularly piscivores and insectivores in AMD stream reaches. Aerial insectivore nesting was less dense and the morphological diversity of AMD streams was negatively affected. The latter result suggests pollutants such as AMD may preclude the capacity for ecomorphological relationships to form along these streams. Acid mine drainage affects the emergent properties of bird communities (e.g. species richness), and potentially more important, negatively affects functional cross-ecosystem dynamics and watershed quality.

55-5 CORDOVA, KL*; BERSIN, TV; SAENGER, EK; JOURNEY, ML; BECKMAN, BR; LEMA, SC; Cal Poly, San Luis Obispo, Northwest Fisheries Science Center; *klcordov@calpoly.edu*

Opposing influences of fasting stress and Igf1 on skeletal muscle gene pathways for Igf-signaling and myofibrillar protein degradation in gopher rockfish

Insulin-like growth factor-1 (Igf1) regulates skeletal muscle growth in fishes by increasing protein synthesis and promoting muscle hypertrophy. In the wild, fish can experience periods of insufficient food intake that can lead to slower muscle growth or muscle wasting, and those changes are linked in part to nutritional modulation of Igf1 signaling. Here, we examined how food deprivation (fasting) affects Igf1 regulation of skeletal muscle gene expression in gopher rockfish (*Sebastes carnatus*) to understanding how food limitation affects Igf-mediated muscle growth. Juvenile rockfish were either fasted or fed (9% mass feed ration per d per g wet fish mass) for 14 d, after which a subset of fish from each group was injected with recombinant Igf1 (1 µg per g body mass) from sea bream (*Sparus aurata*). Fasted fish lost body mass and had a lower body condition factor (k), lower hepatosomatic index, reduced plasma Igf1 concentrations, and lower relative mRNA levels for *igf1* in skeletal muscle. Fasted fish also showed elevated mRNA levels for Igf1 receptors A (*igf1rA*) and B (*igf1rB*) in skeletal muscle, and >4-fold higher gene transcript abundance for muscle-specific F-box protein 32 (*fbxo32*, also called *atrogin-1*), a ubiquitin ligase involved in myofibrillar protein degradation and muscle atrophy. Injection with recombinant sea bream Igf1 increased plasma Igf1 concentrations in both fasted and fed rockfish, and strongly down-regulated gene transcript abundance for *fbxo32*, suggesting that elevated muscle protein degradation during food restriction is mediated in part by a reduced availability of Igf1.

10-2 CORN, KA*; MARTINEZ, CM; BURRESS, ED; WAINWRIGHT, PC; Univ. of California, Davis; *kacorn@ucdavis.edu*

High rates of evolution of cranial mobility are characteristic of suction feeding

Suction feeding is used by every group of aquatic vertebrates and is the primary mechanism of prey capture for most ray-finned fishes. Cranial mobility, or the process of rapidly expanding a mobile skull, is a crucial component of suction feeding. We studied evolution of cranial mobility in suction feeding fishes and compared to fishes that rely on biting. We recorded videos of prey capture by suction in 44 species, including 13 that normally feed by biting prey attached to the substrate. Kinematics of cranial motion were quantified by tracking the change in position of 18 landmarks on the head and body, which were used to generate variables describing components of motion, such as mandible rotation, upper jaw protrusion, and cranial rotation. We analyzed this dataset using a new multivariate, variable rate, state-dependent Brownian motion model of continuous character evolution to estimate rates of kinematic evolution. The diversity of cranial mobility among suction feeders was 10.2 times that of native biters, in association with a 2.4-fold higher rate of evolution of kinematics. Surprisingly, this difference in the rate of feeding motion diversification is not a simple consequence of variation in morphology, as we found that suction feeders have just 1.5 times the disparity in interspecific cranial morphology than biters. With lower rates of kinematic evolution, biters have convergently decreased cranial mobility and each of its components, indicating substantial anatomical and functional constraints on fishes that evolve biting feeding modes. We conclude that diversity in cranial mobility and high rates of kinematic evolution are characteristic of suction feeding and provide a link between feeding mode and the exceptional diversity of suction feeding vertebrates.

56-3 CORREA, AMS*; GRUPSTRA, CGB; HOWE-KERR, LI; VEGLIA, AJ; BRYANT, RL; CONETTA, D; Rice University, Houston, University of Rhode Island, Kingston; *ac53@rice.edu*

Viral Reefscapes: Microbial Interactions with Threatened Coral Hosts and Reef Ecosystems

Coral-associated microbes (e.g., dinoflagellates in the family Symbiodiniaceae, bacteria) contribute to the health and function of their host colonies. Yet, during acute periods of environmental stress, microbial partners can shift or dissociate entirely from hosts, causing colony disease/bleaching and mortality. Shifts in coral-associated viruses are also likely to correlate with differences in coral and reef health, yet relatively few studies target this group. We are exploring the diversity of coral- and dinoflagellate-associated viruses in a range of Pacific and Caribbean host species, in healthy and diseased/bleached coral tissues, and in laboratory cultures of Symbiodiniaceae. We recently examined actively transcribing viruses from the coral, *Pocillopora verrucosa*, and recovered OTUs that aligned with 108 distinct viral groups at several taxonomic levels in a single host colony using RNA-Seq. Viral reads processed to date were dominated by phage (~94%) but also included similarities to members of the Megaviridae, Pandoraviridae, and Alvernaviridae, all of which likely infect Symbiodiniaceae. We characterized lineage-specific diversity in a positive single-stranded RNA virus (Alvernaviridae) in five *P. verrucosa* genets exposed to control and thermal stress treatments using nested degenerate primers and amplicon sequencing, and identified ~2,400 ASVs (N = 55 coral fragments total), and found that the community composition of these viruses is more strongly correlated with coral genet than thermal stress. There have been challenges in confirming the roles of coral-associated viruses, due to the techniques applied and difficulties in culturing these viruses. We discuss the importance of developing a cnidarian-dinoflagellate-virus model system in order to advance our understanding of the roles of viruses in corals and other hosts.

129-5 CORYELL, RL*; NISHIGUCHI, MK; New Mexico State University; *nish@nmsu.edu*

Temperature Adaptation Influences Environmental and Symbiotic Fitness in the Squid-Vibrio Mutualism

Sepiolid squids (Cephalopoda: Sepiolidae) are found in mutualistic partnerships with members of the Vibrionaceae throughout the world. Beneficial microbes that are environmentally transferred between generations of their hosts are exposed to abiotic factors that can eventually influence their symbiotic competence. Therefore, we examined the influence of temperature adaptation on the free-living stage of *Vibrio fischeri* from various hosts and their native temperature regimes. Using *in vitro* experimental evolution, we adapted five strains of symbiotic *V. fischeri* from temperate, tropical, and semi- temperate native ranges. These strains were adapted to five temperatures for 2000 generations to assess the impact of temperature adaptation on symbiotic fitness. Physiological assays of growth, luminescence, biofilm activity, and motility were performed comparing evolved *V. fischeri* lines to their ancestor. Colonization experiments using naïve juvenile squid were performed singly and in competition with their ancestors. Lines evolved at elevated temperature lost their ability to luminesce, especially those from temperate ranges, however, this did not seem to influence colonization efficiency. Evolved lines, regardless of physiological response, gained fitness compared to their ancestors when colonizing a host after 1000 generations while, in some cases, lost this advantage after 2000 generations. Our results indicate that evolved *V. fischeri* are able to compensate for their altered physiology, influencing colonization fitness. These findings will help determine whether changes in environmental conditions such as temperature will be detrimental to the establishment of symbiotic associations, and therefore have a much greater impact on beneficial microbes that contribute to the overall health of metazoan life.

59-6 COSTA, D.P*; KIENLE, S.S; TRUMBLE, S.S; KANATOUS, S.; GOEBEL, M.E; BORRAS, R; CROCKER, D.E; University of California at Santa Cruz, Baylor University, Colorado State University, National Marine Fisheries Service-NOAA, Chilean Antarctic Program, Sonoma State University; *costa@ucsc.edu*

Foraging Behavior and Movement Patterns of the Leopard Seal in the Antarctic Peninsula

The Antarctic Peninsula is one of the most rapidly changing habitats in the world. To better understand the ability of the leopard seal, an apex predator in the Antarctic ecosystem, to cope with a changing environment, we examined the foraging behavior and habitat utilization of leopard seals using satellite telemetry. We deployed 12 satellite-linked tracking devices on 3 adult males, 8 adult females, and one juvenile female leopard seal on Cape Shirreff Livingston Island, Antarctica during April-May 2018. The animals ranged from 147 to 540 kg with a mean mass of 389 ± 95 kg. Three of the twelve leopard seals remained within the South Shetland Islands, while two female seals transited well to the northeast, with one stopping at South Georgia Island. On average leopard seals made short shallow dives with a mean depth of 28 ± 7 sd meters and a duration of 3.8 ± 0.5 sd min. However, they occasionally made deep dives, with the single deepest dive being to 428 m and lasting 10.1 minutes. Their physiological parameters were consistent with a shallow aerobic diver, with a blood volume of 134 ± 5.2 sd ml/kg. Their hematocrit ranged from 44 – 56 with a mean of 51 ± 4 sd. We determined myoglobin concentrations in the locomotor muscles 6 of the animals and those ranged between 44.9 ± 1.4 se mg/gr for Longissimus dorsi and 32.9 ± 0.8 se for pectoralis muscle. Information on their habitat requirements can be used to predict how their habitat might shift as the climate changes.

81-2 COSTA, D.P*; HUCKSTADT, L.A; University of California at Santa Cruz; *costa@ucsc.edu*

Incorporating the movement of Marine Megafauna is critical to developing appropriate marine protected areas

Movement patterns of marine megafauna vary broadly, from species that are highly resident moving no more than tens of kilometers over their lifetime, to species that migrate over tens of thousands of kilometers each year. Marine Protected Areas have been proposed as a conservation tool for protection. However, while the characteristics of MPAs appropriate for marine invertebrate species has been considered, the issues surrounding the development of MPAs for highly migratory species is only just being considered The potential risk (sensitivity and exposure) to individuals within a population will vary in response to how they move in space and time. Some species move throughout their species range whereas others cover only a very small proportion of the species range. Some highly migratory species have foraging areas that are spatially distinct from their breeding areas, which are then connected by migration. Movement patterns are therefore critical to provide insight into the proportion of the population that would be protected within a specific MPA and which activity (i.e., feeding, migrating, and breeding) would be protected.

2-6 COSTELLO, RA*; COOK, PA; FORMICA, VA; BRODIE III, ED; University of Virginia, Swarthmore College; *rac2zb@virginia.edu*

Habitat Structure Influences Sex-Specific Patterns of Multilevel Selection in Experimental Populations of Forked Fungus Beetles

Multilevel selection occurs when a group phenotype influences individual fitness above and beyond the effects of individual traits. Patterns of multilevel selection are largely unexplored, yet understanding what drives multilevel selection is critical for revealing when group traits may evolve. Social networks provide a unique opportunity to study multilevel selection, as social networks quantify complex social interactions at both the individual and group levels. In this study, we used experimental populations of forked fungus beetles (*Bolitotherus cornutus*) to measure the effects of both individual position within a social network and emergent group-level social network characteristics on individual fitness. We found that male beetles that hold positions of high strength in social networks by interacting more often and with more conspecifics had higher mating success. However, the emergent group-level social network connectedness did not influence male mating success. Conversely, we found that individual strength had no effect on female reproductive success but that females in experimental populations with many social interactions and high network connectedness had lower reproductive success. We additionally manipulated the distribution of fungal resources in the experimental populations to explore how habitat structure influences patterns of multilevel selection. We found that females in more connected networks laid fewer eggs only when fungal resources were distributed in discrete clumps. Our results suggest that patterns of multilevel selection differ across the sexes and across habitat structures.

33-4 COUGHLIN, DJ; Widener University, Chester, PA; *djcoughlin@widener.edu*

Thermal Acclimation Studies in Cold-Water Fishes: Do They Reveal the Potential Impact of Climate Change?

As climate change alters the thermal environment of the planet, interest has grown in how animals may mitigate the impact of a changing environment on physiological function. My students and I have been examining how thermal acclimation alters swimming performance, muscle contractile properties and the gene expression and protein content of myotomal muscle in several cold-water fishes. Thermal acclimation to a warm environment may, for instance, blunt the impact of a warming environment on metabolism by allowing a fish to shift to slower isoforms of metabolically significant proteins such as myosin heavy chain. Our studies of rainbow smelt (*Osmerus mordax*) and three salmonids – Atlantic salmon (*Salmo salar*), rainbow trout (*Oncorhynchus mykiss*) and brook trout (*Salvelinus fontinalis*) – reveal a range of responses to thermal acclimation that suggest that the impact of climate change will be highly variable, even amongst related species. Smelt show a substantial thermal acclimation response, with significant shifts in swimming performance, muscle contractile properties and gene expression with changes in environmental temperature. Alternatively, young salmon displayed very little thermal acclimation response, suggesting they may be more substantially impacted by climate change. Brook trout and rainbow trout show intermediate thermal acclimation responses compared with smelt and salmon, with modest changes in muscle function with changes in thermal environment. How variations in thermal acclimation capacity will relate to species survival in the face of climate change remains an open question.

S1-7 COUNTWAY, PD*; MATRAI, PA; Bigelow Laboratory for Ocean Sciences, East Boothbay, Maine; *pcountway@bigelow.org*

Antarctic Microbial Interactions Revealed by Continuous Flow Incubation and Variable Rates of DMSP Supply

Interactions between bacteria and protists drive ecosystem processes and contribute to the overall diversity, structure, and function of marine plankton communities. These interactions occur through direct cell-to-cell contact or via cell metabolites that provide biochemical and ecological linkages among diverse groups of organisms. One metabolite, the phytoplankton-derived compatible solute dimethylsulfoniopropionate (DMSP), may play a key role in structuring Antarctic microbial assemblages. A series of experiments were performed to investigate microbial interactions related to DMSP cycling during the austral summer (2017) and fall (2018) at Palmer Station (Anvers Island, Antarctica). The diversity, structure, and function of Antarctic plankton communities were investigated through seawater incubation experiments conducted in both continuous and batch modes. Incubation bottles containing natural microbial assemblages were supplied with nutrient- and DMSP-amended filtered seawater with two different supply rates. Batch treatments served as controls for the continuous cultivation. Overall, the supply of DMSP was depleted very quickly, likely via bacterial DMSP demethylation and lyase pathways, with evidence for a wide variety of DMSP genes in coastal Antarctic waters. The summer microbial assemblage was characterized by relatively low levels of bacterial diversity while substantially higher levels of bacterial diversity were detected during the fall. Evidence suggests that the supply rate of DMSP influenced the structure of microbial assemblages for both bacteria and protists. This experimental design opens the door to quantify additional protist-bacteria interactions in aquatic environments.

101-5 COX, CL*; ROSSO, AA; NICHOLSON, DJ; MCMILLAN, WO; LOGAN, ML; Florida International University, Georgia Southern University, Queen Mary University London, Smithsonian Tropical Research Institute, University of Nevada-Reno; *clcox@georgiasouthern.edu*

Sex-biased Parasitism and the Expression of a Sexual Signal in a Tropical Forest Lizard

Sexual signals are usually strongly linked to reproductive success and fitness. Because these signals are often but not always expressed more highly in one sex than the other, they can impose a sex-specific cost of reproduction. One mechanism whereby sexual signal expression can inflict a cost of reproduction is parasitism, which can reduce performance, survival, and reproduction. We tested the relationship between expression of a sexual signal (the dewlap) and ecological, morphological, and energetic factors mediating ectoparasite (mite) load in the Panamanian slender anole (*Anolis apletophallus*), using a combination of field and laboratory studies. We found that males were more highly parasitized than females, and that this relationship was driven by the preponderance of ectoparasites on the larger dewlap of males. Indeed, ectoparasite infection increased with both body size and dewlaps size in males but not females. We found no relationship between ectoparasite load and either habitat use or field-active body temperature. Energetics was related to parasite infection in a sex-specific fashion, as male anoles with smaller fat stores had higher mite loads, whereas there was no relationship between mite infection and fat body mass in females. In contrast, we found that the size of the gonads was positively associated with the number of mites in females, but not in males. Our results suggest that the expression of the sexual signal could incur a sex-specific fitness cost that is distinct from testosterone-based immunosuppression and may play a role in structuring life-history tradeoffs.

104-3 COX, RM*; WITTMAN, T; ROBINSON, CD; COX, CL; JOHN-ALDER, HB; University of Virginia, Georgia Southern University, Rutgers University; *rmc3u@virginia.edu*
Sex steroids as mediators of phenotypic integration, genetic correlations, and evolutionary transitions
Comparative endocrinologists have increasingly adopted evolutionary approaches not only to characterize the evolution of the endocrine system itself, but also to leverage it as a framework for exploring basic evolutionary principles. For example, by virtue of their massively pleiotropic effects on the expression of genes and phenotypes, sex steroids and their receptors are predicted to (1) structure the patterns of phenotypic variance and covariance that are available to natural selection, (2) alter the underlying genetic correlations that determine a population's evolutionary response to selection, and (3) facilitate evolutionary transitions in fitness-related phenotypes via subtle regulatory shifts in underlying tissues and genes. We present experimental support for each of these predictions by focusing on the specific case of androgen-mediated gene expression and sexual dimorphism in growth and ornamentation of *Anolis* and *Sceloporus* lizards. A central theme to emerge from these studies is that the rapidly increasing availability of genomic and transcriptomic data from non-model organisms places evolutionary endocrinologist in an excellent position to address the hormonal regulation of the key evolutionary interface between genes and phenotypes.

16-8 COYLE, J.A*; LOLAVAR, A.A; MEREDITH, T.L; Florida Atlantic University; *jashcra1@fau.edu*
Developing a multidisciplinary, undergraduate research training program for dual enrolled students
Florida Atlantic University High School (FAUHS) is a public, dual enrollment high school on the campus of Florida Atlantic University. FAUHS students begin college full time at FAU following a rigorous 9th grade year and typically accumulate 3-years' worth of college credit by the time they graduate high school. To ensure the students are prepared and qualified to enter graduate programs 1 year after high school graduation, we created a program to guide them through undergraduate research experiences at FAU. The FAUHS Research Program supports students in conducting undergraduate research and scholarly inquiry in a variety of disciplines, while helping them navigate aspects related to minors conducting research in a university setting. This support is scaffolded into three levels - exposure, skill-building, and intensive research experience - and consists of a series of research methodology courses, individualized mentoring, and access to the FAUHS Owls Imaging Laboratory (OI Lab). The research program goals include introducing the students to research being conducted at the university; developing basic, commonly-used research skills; finding a faculty research mentor; developing a research project proposal; finding and applying for research funding; performing data analysis; and presenting and publishing research results. The OI Lab is a research space within the high school where students can actively conduct research with or without a university mentor. University researchers use the lab in exchange for mentorship of FAUHS students. This program enables the students to strategically refine their career paths, build transferable skills, effectively compete for future opportunities, and make a real impact in their discipline.

69-1 CRAIN, DD*; USENKO, S; MANSOURI, F; WINFIELD, ZC; ZERBINI, AN; GABRIELE, C; SABIN, R; POTTER, C; TRUMBLE, SJ; Baylor University, Waco, TX, Marine Mammal Laboratory, Seattle, WA, Glacier Bay National Park and Preserve, AK, Natural History Museum, London, Smithsonian Institution, Washington, DC; *dani_crain@baylor.edu*
A Different Kind of Wax Museum: Forecasting Population Trajectories of Baleen Whales Using Reproductive Parameters From Earplugs.
Reliable estimates of baleen whale growth rates are difficult to obtain when sampling populations at low densities and/or in complex habitats. We evaluate baleen whale population dynamics by analyzing progesterone in baleen whale waxy earplugs (N = 11, total lamina = 835, age range = 13 – 63 years). To identify pregnancies, we calculated percent change in progesterone from the previous lamina, ranked these points, then assigned the top 30% of points as pregnancies. From these pregnancies, we estimated age at first pregnancy, pregnancy intervals, and pregnancy rate. Our results matched well with published calving intervals, age at first birth, and birth rate. Next, we compared multiple individuals for age-specific fecundity (aligned by age). Our results demonstrated, for the first time, age-specific fecundity in fin whales (n = 3, total lamina = 117) and reproductive senescence beginning at 25 years, theoretically reaching zero fecundity at 55.5 years. Finally, we modeled the average rate of increase (ROI) of fin whales using a ROI model which includes age-specific fecundity and reproductive senescence. Compared to the standard ROI model, our results suggest a 19.7% reduction in future population size when projecting the ROI from each model forward to the year 2050. Using a model that incorporates age-specific fecundity and reproductive senescence is important to effective management and can be used to assess how exposures to stressors can impact vital rates of baleen whale populations over the long-term.

9-4 CRALL, JD*; EASTON-CALABRIA, A; CRONIN, K; THUMA, J; DEY, B; FORD VERSYPT, A; DE BIVORT, BL; Harvard University, Tufts University, Princeton University, Oklahoma State University; *jcrall@oeb.harvard.edu*
The social scaling of stress-sensitivity: Understanding the impacts of pesticide exposure and temperature stress in bumblebee colonies
Social insects such as ants, bees, and wasps are ecologically and evolutionarily dominant animals that provide critical ecosystem services such as pollination. While both theoretical and empirical studies suggest that the degree of sociality (i.e., colony size or degree of division of labor) plays a critical role in resilience to stressors such as pesticides, the specific behavioral mechanisms underlying these impacts remain unclear. Here, we use a combination of empirical and modeling approaches to explore how colony size affects sensitivity to environmental stressors (particularly pesticides and temperature fluctuations). By developing an agent-based model parameterized on detailed behavioral data, we show that colony size mitigates the impacts of exposure to imidacloprid in *Bombus impatiens* colonies. Next, we describe recent experiments combining automated individual tracking with high-resolution thermal imaging to study how the synergistic effects of temperature fluctuations and pesticide exposure change during colony development in bumblebees (*Bombus impatiens*, *Bombus bimaculatus*, and *Bombus griseocolis*). Finally, we highlight the potential of combining modeling and high-throughput, empirical tracking techniques for exploring central questions in collective resilience of bumblebees and other social insects.

14-2 CRANE, RL*; DENNY, MW; Stanford University, CA; *rlcrane@stanford.edu*

Resistance and Repair of Mechanical Fatigue in Mussel Shells

Like other rigid armors, bivalve shells protect from potentially lethal predatory and environmental threats that range in frequency and magnitude from single powerful predator strikes to repeated insults from ocean waves. Shells' effectiveness at defending from such forces is often quantified with a test of one-time breaking stress (strength): a shell is compressed until it breaks. However, this technique cannot reveal how shells resist mechanical fatigue, a process by which repeated, subcritical stresses weaken and break a material. Furthermore, the long-term threat posed by fatigue hinges on the animal's capacity for repair. We quantified and contextualized fatigue resistance and repair in the California mussel (*Mytilus californianus*) to identify the ecological threat of fatigue. We used two tests of fatigue resistance: applying a subcritical load constantly or cyclically until fracture. Mussel shells broke when fatigued such that lower forces required longer loading periods before fracture. We also measured the ability of live mussels to repair non-lethal fatigue damage (15 cycles at 67% of predicted strength) over one month. Shells were weakened by fatigue but, on average, repaired within one week. Strong predators can fracture shells with a single impact, and low forces (e.g., a shell clamping shut) won't cause damage on ecologically relevant timescales. Fatigue can make intermediate forces a threat, though; weaker predators can fatigue otherwise inaccessible prey, and failed predation attempts and episodic threats (e.g., hurled debris) can weaken shells. However, mussels have the capacity for speedy repair. A mussel would have little recourse during one predator attack, but one week between threats is sufficient for repair. Rapid, repeated forces can break shells, but, if survived, do not cause irrecoverable lifelong damage.

40-5 CRAWFORD, CH*; CERRATO-MORALES, CL; FLAMMANG, BE; New Jersey Institute of Technology; *crawford.callie@gmail.com*

Comparative Kinematics of Terrestrial Walking in Two Balitorid Loaches

Hillstream loaches (Balitoridae) inhabit the fast flowing hillstreams of South and Southeast Asia. These fishes have evolved behavioral and morphological characteristics necessary to survive in these torrential streams, including the evolution of a robust pelvic girdle modified sacral ribs. The modified ribs create a skeletal connection between the vertebral column and the puboischiadic plate. Previous researchers have suggested that this connection likely evolved as a means of facilitating station holding in their rheophilic environment. We expect the tetrapod-like walking behaviors observed in balitorids to be facilitated by this skeletal connection. Within the family there is variation in the amount of modification of the sacral rib which can be divided into three morphotypes: 1, elongated sacral ribs with similar thickness to anteriorly adjacent ribs; 2, enlarged and elongated sacral ribs; and 3, enlarged and elongated sacral ribs with a flared crest. All three morphotypes have the sacral rib inserting at the lateral foramen of the pelvic plate and secured via a ligamentous support. We hypothesize that increased pectoral girdle stability will result in greater terrestrial walking performance. Performance is measured by comparative kinematic variables including timing of fin placement; walking velocity; and fin, head, and tail angle. Here we compare the walking kinematics of two species of hillstream loaches, *Homaloptera parclitella* and *Cryptotora thamicola*, which exhibit morphotypes 1 and 3 respectively.

119-3 CRAWFORD, K*; ALBERTIN, CB; KOENIG, KM; ROSENTHAL, J; St. Mary's College of Maryland, St. Mary's City, MD, Marine Biological Laboratory, Woods Hole, MA, Harvard University, Cambridge, MA ; *kcrawford@smcm.edu*

CRISPR-Cas9 Genome Editing in the Cephalopod Doryteuthis (Loligo) pealeii

Cephalopods exhibit complex behaviors and have the largest nervous systems among the invertebrates. Their large brains and sophisticated neural networks allow them to interact with and respond to their environment with astounding speed and specificity. Cephalopods, most notably the longfin inshore squid, Doryteuthis (Loligo) pealeii, have and continue to play a critical role in our understanding of neural function. Although the mechanisms that direct their development are only now being approached at the molecular level, as genome and transcriptome resources for cephalopods become available, the time is ripe for developing genome editing technologies, such as CRISPR-Cas9, for use in cephalopods. We chose the gene for the enzyme tryptophan dioxygenase (TDO) to target in our experiments. TDO is an enzyme that is necessary for the production of the ommachrome pigments which color the chromatophores and the retina. Successful editing of TDO with CRISPR Cas9 should result in mosaic embryos with regions lacking pigmentation. In this study, in vitro fertilized D. pealeii embryos were injected with Cas9 preincubated with a CRISPR gRNA targeting TDO and cultured to hatching. Injected embryos developed normally and possessed discrete regions of ¼ to ½ albinism. Partial albino embryos were all positive for INDELs in TDO, suggesting that our CRISPR-Cas9 mutagenesis was successful. This study demonstrates for the first time that genome editing studies and the generation of transgenic animal lines are possible for cephalopods. This work was supported by an MBL Fellowship to KC and an NSF EDGE grant (1827509) to our team.

S3-5 CROFTS, SB*; SMITH, SM; ANDERSON, PLS; CROFTS, Stephanie; UIUC, Field Museum of Natural History, 1984; *scrofts@illinois.edu*

Crushing and puncturing: biomechanics of tooth shape

The tight relationship between tooth morphology and food material properties is often used to make inferences about an organism's ecology and diet. Certain basic tooth shapes have been tightly tied to trade-offs associated with inducing fracture in different food items. For example, teeth used to puncture tough, deformable tissues can be modeled as relatively tall, narrow cones that balance tip sharpness with avoiding failure via buckling. Crushing teeth, alternatively, can be modeled as low rounded or flattened cones, which fracture brittle shells while resisting failure themselves. Simplified models such as these can be useful, but it is important to remember that teeth are more than simple cones. There are levels of complexity to tooth form and function, and secondary structures can be important to tooth function. The cusps of mammalian teeth are a well studied example of secondary tooth structures, whereas surface complexity and secondary structures occurring in non-mammalian taxa have been generally less studied. Ridges or edges, sharp raised features running from the tip of the tooth along the long axis, are one example of an easy to model secondary structure. Hypothesized purposes for these ridges include: reducing work to fracture, better gripping of food particles, and resisting biting stresses. Teeth used to cut tough materials, like skin and muscle, typically have bladed edges which serve to reduce required work. Similar but more numerous ridges occur in many tetrapods, and may be associated with durophagy and/or herbivory. Here we use biomechanical models to test hypotheses regarding ridge function under different loads, number and arrangement affect function, and how this interacts with overall tooth shape.

95-6 CROSIER, AE; BAPODRA, P; SANTIESTEVAN, J; COMIZZOLI, P; PLACE, NJ*; Smithsonian Conservation Biology Institute, Front Royal, VA, Columbus Zoo and Aquarium, Powell, OH, Cornell University, Ithaca, NY; *njp27@cornell.edu*

Anti-Müllerian hormone as a predictor of responses to ovarian stimulation in cheetahs, Acinonyx jubatus

Serum anti-Müllerian hormone (AMH) concentrations have been shown to predict the ovarian response to exogenous gonadotropin stimulation for assisted reproductive technologies (ARTs) in women and production animals. Our objective was to determine if the same holds true for cheetahs. In anticipation of planned artificial inseminations (AI), six cheetahs underwent ovarian stimulation with a standard eCG/LH protocol. Within one month before eCG, a blood sample was collected for serum AMH determination. A second blood sample was collected approximately 42 hours post LH and before laparoscopic intra-oviductal AI, when the total number of corpora lutea (CL) were enumerated. Pre-eCG AMH concentrations were 1.00-3.09 ng/mL, and the number of CL ranged from one to 17. Females appeared to segregate into high and low AMH groups (N = 3 each), defined by AMH greater than 2.00 ng/mL (range 2.14-3.09 ng/mL) or substantially less than 2.00 ng/mL (range 1.00-1.15 ng/mL). The number of CL (mean ± STD) for the high AMH group was 10.6 ± 6.0, and for the low AMH group was 3.7 ± 3.1. The pre- and post-gonadotropin AMH concentrations were significantly correlated ($r2 = 0.66$, $p = 0.03$), and females with a high pre-AMH concentration uniformly showed a decline in AMH post-eCG/LH. Females with a low pre-AMH concentration did not have consistent changes in AMH following eCG/LH. While additional females are being recruited to this study, the results from the initial cohort suggest AMH is likely to be a good predictor of individual responsiveness to ovarian stimulation in preparation for ARTs in cheetahs.

66-7 CROWELL, HL*; TAYLOR, EN; University of Michigan, California Polytechnic State University; *hlcrowel@umich.edu*

Comparative Thermal Ecology of Coastal and Inland Populations of Pacific Rattlesnake Crotalus oreganus

Reptiles have become focal organisms for studying the direct effects of changing climates due to their reliance on environmental temperatures for physiological functions. In this study, we compared thermal and behavioral data collected during 2010-2017 from four distinct populations of *Crotalus oreganus* on the central coast of California to examine how climate change will impact closely related populations inhabiting distinctly different climates. Using biophysical temperature models, surgically implanted temperature data loggers, and radiotelemetry, we collected data on the thermal microhabitats available as well as field active body temperatures for 85 individual snakes. Along with lab-derived preferred body temperature range, we determined the thermal accuracy of each snake population. Snakes from hot, inland populations thermoregulated most accurately, despite inhabiting more thermally constrained environments. We then used a climate change model at a 1°C and a 2°C increase to predict changes in habitat thermal quality and theoretical changes in snake standard metabolic rates. In both coastal and inland areas, the availability of annual thermally favorable temperatures is predicted to increase with increasing ambient temperatures. Additionally, a theoretical increase in body temperature of 1 and 2 °C would have a minute impact on the overall energetic needs of snakes, still allowing them to meet baseline energetic requirements with only one large meal a year. Small increases in ambient temperature will most likely have little impact on rattlesnake thermal ecology, as our findings suggest that these animals are fairly precise thermoregulators, maintaining relatively constant body temperatures regardless of extreme thermal variation in their surrounding habitats.

99-7 CUFF, AR; BISHOP, PJ; MICHEL, KB; GAIGNET, R; HUTCHINSON, JR*; Structure & Motion Lab, Royal Veterinary College, United Kingdom; *jrhutch@rvc.ac.uk*

Anatomically Grounded Estimation of Limb Muscle Sizes in Archosauria

It is commonly assumed that "muscle scars" on bones correspond to the cross-sectional areas of muscle-tendon units. This issue is vital both for understanding morphology itself (e.g. musculoskeletal integration) and for reconstructing musculoskeletal form in extinct taxa. Archosaurian reptiles famously evolved disparate skeletal forms with differences in body size, posture, gait and other aspects of locomotion reflected by variations of the muscle attachments. We tested how well hindlimb muscle sizes can be predicted from skeletal evidence in archosaurs. With a high-precision manual digitizer (±0.01mm), we digitized the bony attachment areas (AA) of all major hindlimb muscles in five juvenile Nile crocodiles and five Elegant-crested tinamous. Additional, lower-precision (~±1mm) older digitized data from an adult ostrich, emu, turkey and chicken were added to our avian dataset for comparison. We measured the physiological cross-sectional areas (PCSAs) of the same muscles for all specimens via dissection. Our prediction was that fleshier attachments would give more consistent estimates of muscle PCSA from AA, whereas more tendinous attachments would have more variable PCSA estimates from AA within and across taxa. Examining how well homologous muscles in Crocodylia and Aves preserve consistent PCSA:AA ratios, we found that only a few muscles do. Finally, we show examples how these ratios can be analysed in a phylogenetic context across Archosauria, applying them to fossil specimens; vs. other methods from the literature.

22-3 CULUMBER, ZW; University of Alabama in Huntsville; *zwc0001@uah.edu*

Variation in Animal Personality Across a Major Environmental Gradient

Theory indicates that animal personality should arise in association with predictable life history trade-offs. Environmental gradients are common in the wild and generate predictable trade-offs, yet we have limited knowledge of how animal personality varies at broad spatial scales. Here, I examined variation in a suite of behaviors in 18 populations of a livebearing fish across latitude, one of Earth's major environmental gradients. Consistent with environmental variation across latitude, and with observed variation in life history traits, personality changed across latitude. Individuals from high latitudes tended to be less social, more bold, and more active than counterparts from lower latitudes, potentially associated with the need to grow and reproduce quickly in regions with shorter seasons and more extreme winters. Overall, these results indicate that animal personality changes in a predictable manner along a major environmental gradient, with potential implications for broader evolutionary patterns.

92-5 DA SILVA, DP*; GOMES, FR; University of Sao Paulo; *diego.pnds@gmail.com*

Interplay between personality, physiology, and temperature in American bullfrogs

Personality has been identified in several different ecological contexts. However, the physiological mechanisms underlying different animal personalities are still poorly understood. Different personalities have been correlated with different patterns of activity and reactivity of the hypothalamus-pituitary-adrenal axis and the resulting plasma corticosteroid levels. Amphibian studies in personality literature are scant. The objective of this study was to broaden the literature on amphibian personality and understand how it correlates with plasma levels of corticosterone (CORT) and testosterone (T), as well as to identify how a chronic high temperature stress might affect behaviour and physiology. Thirty male American bullfrogs were brought from a local farm into laboratory conditions - summer photoperiod (13:11 LD), 28±1°C. Blood was sampled after 15 days of habituation to assess each individual's basal plasma levels of CORT and T. Animals were then submitted to behavioral tests and we assessed activity, bold, and exploratory behavior. After this initial phase (42 days), animals were divided into two groups: control (28±1°C (n = 15)) and experimental (34±1°C (n = 15)). Blood was sampled again from both groups 12 hours, 25 days, and 46 days after animals from the experimental group were transferred to the high temperature treatment. Furthermore, all 30 animals were resubmitted to the behavioural tests 1 month after the temperature treatment began, in order to verify if personality traits remained the same through time and through the experimental treatment. All tests were video recorded and will be analyzed in a tracking software. We will test for the existence of behavioural syndromes, for the association between personality and physiology, and how increment temperature modulates these associations.

66-5 DAHLHOFF, VC*; LARKIN, B; WOODS, HA; DAHLHOFF, Vic; University of Montana, MPG; *victoria.dahlhoff@umontana.edu*

Capturing behavioral thermoregulation in the western tent caterpillar Malacosoma californicum pluviale using thermal imaging

Several traits characterize colonial living in animals, but an especially important one is modification of environmental temperature. Colonial insects are some of the most common animals known to create structures that alter thermal conditions of the group. Because insects are ectotherms and rely on their environmental temperature to regulate body temperature and thus rates of metabolism, the ability to control environmental temperature is especially crucial. Here I describe mechanisms of thermal modification in the Western tent caterpillar, *Malacosoma californicum pluviale*. Tent caterpillars build communal silk tents, which can be heated to temperatures substantially above ambient air temperature. In spring 2019, I quantified how individual caterpillars are experiencing this extra heat. Using IR thermal imaging I captured body temperatures of caterpillars in the following combinations: grouped on the tent, alone on the tent, grouped off the tent, and alone off the tent. I found that caterpillars grouped together off the tent had somewhat elevated body temperatures above solo caterpillars - a result that was replicated using operative temperature models. However, grouped caterpillars on the tent reached much higher temperatures, suggesting that the tent is capturing extra heat. My data suggest that the tent plays an important role in maintaining a more buffered thermal environment for caterpillars over and above its function as a platform for behavioral thermoregulation.

S10-4 DAKIN, R*; SEGRE, PS; BERBERI, I; ALTSHULER, DL; Carleton University, Stanford University, University of British Columbia; *roslyn.dakin@gmail.com*

Multilevel analysis of maneuvering performance and morphology in hummingbirds

The ability of a flying animal to maneuver can be critical for survival. How do morphological traits determine agility? To address this question, we developed an approach to analyze thousands of rotations, accelerations, and turns, as the geometrical building blocks of complex flight. To relate morphology to maneuverability, we recorded flight performance from over 200 individuals in 25 hummingbird species. We used multilevel regression models to analyze variation both within and among species, accounting for phylogenetic nonindependence. The advantage of the comparative approach is that evolution repeatedly explores new variants, making it possible to determine the contribution of several morphological and biomechanical traits. We found that larger hummingbird species have evolved disproportionately larger wings and muscle capacity, which allows them to outmaneuver smaller species (overcoming their size-based disadvantage). This demonstrates how multilevel models can be used to reveal compensatory evolution. Our current work investigates whether species differ in the predictability of flight maneuvers. We will address whether predictability and the level of performance are associated with different morphologies, representing a potential tradeoff.

114-4 DANFORTH, SM*; LARSON, JG; DAVIS RABOSKY, AR; MOORE, TY; Univeristy of Michigan, Ann Arbor, MI; *sdanfort@umich.edu*

A Kinematic Analysis of Micrurus Coral Snake Thrash Duration and Curvature Enables Quantitative Characterization of Non-Locomotory Behavioral Motion

Warning signals in chemically defended organisms greatly impact the outcome of predator-prey interactions. These aposematic signals are often composed of high-contrast color patterns combined with complex behavioral movements with little locomotory function. When threatened by a predator, venomous coral snakes (genus *Micrurus*) display a vigorous, non-locomotory thrashing behavior that has been only qualitatively described. This thrashing display is likely a key component of a complex aposematic signal under strong stabilizing selection across species in a mimicry system. We analyzed variation in the presence and expression of the thrashing display across five species of South American coral snakes by experimentally testing snake response across simulated predator cues. We measured the duration of each thrash and the curvature along the body during the resting period after each thrash. These kinematic analyses can be performed with minimal animal handling and can cope with multiple self-occlusions and acute curvatures. We found significant variation in the propensity to perform a display at all, the duration of thrashing, and the curvature of snake bodies. This variation was mediated by predator cue type, snake body size, and species identity. Our results suggest that a high degree of variation persists in thrashing behavior exhibited by *Micrurus* coral snakes despite presumably strong selection to converge on a common signal. This quantitative behavioral characterization presents a new framework for analyzing the ecologically relevant motions displayed by elongate organisms.

132-2 DANIELS, J*; OSBORN, K; AOKI, N; HAVASSY, J; MUSHEGIAN, N; KATIJA, K; Monterey Bay Aquarium Research Institute, Moss Landing, CA, Monterey Bay Aquarium Research Institute, Moss Landing, CA and Smithsonian Institution, Washington, DC, Smithsonian Institution, Washington, DC, Smithsonian Institution, Washington, DC; *joost@mbari.org*
A Midwater Polychaete on the Move: Swimming of Tomopteris
Tomopterids are a family of highly-derived, holopelagic, gelatinous polychaetes found throughout the world's oceans. The lack of internal segmentation and chaetae combined with their large paddle-like appendages (parapodia) distinguish tomopterids from other polychaetes. Paddling of the fleshy parapodia and lateral body motion allow these animals to swim with a speed and maneuverability that are visually distinct from other swimming polychaetes, such as nereids. We captured living tomopterids using remotely operated vehicles in California's Monterey Bay and transferred them to filming vessels onboard the ship. Swimming motion (kinematics) of the animals was studied using high-speed video recordings of the animals. We found that active paddling of the parapodia generates forward thrust, augmenting the thrust derived from the forward-directed body wave during straight, forward-directed swimming. In addition, this body wave allows for increased range of motion of the parapodia, resulting in an increased displacement of the body per stroke. The characteristics of the stroke deviate from existing metachronal simplified models for polychaetes and crustaceans alike, and a drag/thrust model is presented based on a simplified *Tomopteris* body plan. These results could have applications in biomimetics and soft robotics.

80-4 DANTZER, B*; VAN KESTEREN, F; PALME, R; BOUTIN, S; MCADAM, AG; LANE, JE; University of Michigan, University of Veterinary Medicine Vienna, University of Alberta, University of Guelph, University of Saskatchewan; *bendantzer@gmail.com*
Disentangling how multiple ecological factors impact glucocorticoids in red squirrels
It is widely appreciated that glucocorticoid levels are impacted by environmental factors such as weather conditions, food availability, the degree of competition over some limited resource, and predation risk. These changes in glucocorticoids can in turn mediate plasticity in behavioral or life history traits that increase the ability of an organism to persist through environmental fluctuations. Although numerous studies have documented the impacts of specific environmental factors on glucocorticoid levels in a wide-variety of organisms, few studies have simultaneously investigated the relative impacts of multiple ecological factors on glucocorticoid levels. Given that free-living animals likely experience environments in which multiple ecological factors are changing in unison, it is important to assess whether their effects are additive, interactive, or mitigating. For example, an increased predation risk may typically be associated with increased glucocorticoid levels in prey but those effects may be mitigated or eliminated by a simultaneous increase in per capita food availability. We assessed the relative effects of weather conditions, food availability, competition, and predation risk on fecal glucocorticoid metabolite levels of North American red squirrels in the Yukon, Canada. We will describe the results from these analyses that use >10 years of fecal glucocorticoid metabolite data collected from free-living red squirrels that experienced natural and experimental variation in weather, food, competition, and predation risk. By doing so, we illustrate the importance of testing multiple hypotheses regarding the ecological causes of variation in glucocorticoid levels of wild animals.

78-4 DARCY, HE*; ANDERSON, PSL; University of Illinois Urbana-Champaign; *hdarcy2@illinois.edu*
Do aquatic paedomorphs converge in both morphology and performance across phylogeny in Spelerpini Salamanders?
The lungless salamander tribe Spelerpini (Caudata:Plethodontidae) presents an opportunity to study the evolution of aquatic species that arose from terrestrial lineages in a phylogenetic context. Two of five genera (*Eurycea* and *Gyrinophilus*) include both aquatic and terrestrial species, the remainder are terrestrial. Additionally, five of the 16 aquatic *Eurycea* have troglodytic morphology characterized by reduced eyes and elongate skulls relative to surface-dwelling paedomorphs. Here, we examine if the morphological changes associated with habitat shifts are convergent. We expect species to show convergence due to shared demands, informed by our understanding of hydrodynamics. Relative to terrestrial species, aquatics must deal with different fluid dynamics during locomotion and feeding as well as support gill arches. However, convergence may be in functional ability and not towards a single morphology, as in herbivorous lizards. To explore if salamanders follow the same pattern, we examined species of the tribe Spelerpini, capturing terrestrial and both aquatic morphologies. We gathered 3D microCT scan data from online repositories and by scanning specimens from the Field Museum of Natural History and the Illinois Natural History Survey. A geometric morphometric analysis of the overall head shape of adults from all three habitats captures gross morphological disparity We create a phylomorphospace to show differences between aquatic and terrestrial species and how phylogeny influences the evolution of aquatic groups. These results allow us to test whether aquatic taxa group are closer together in morphospace than their terrestrial sister groups or show parallel trajectories similar to what's been found in herbivorous lizards.

81-1 DAVID, K T*; FAN, Z; HALANYCH, C N; HALANYCH, K M; Auburn University; *kzd0038@auburn.edu*
Are Two Genomes Better Than One? Ploidy Correlates Species' Distributions in South American Frogs
Polyploids are organisms with more than two sets of homologous chromosomes. Polyploids may experience fitness advantages over their diploid counterparts due to increased benefits from effects such as heterosis (hybrid vigor) and gene redundancy. However, as polyploid individuals are formed spontaneously, matings between them are statistically unlikely. Additionally, if matings occur between polyploids and diploids the resulting offspring will be unviable, and as a result it is unlikely to see diploids and polyploids occurring sympatrically. To explore these ideas, we collected 5,660 observations from 75 species across the 5 South American frog genera with verified polyploid members. We recovered a negative correlation between polyploid and diploid occurrences as well as close spatial associations in polyploids across genera. Where diploids are distributed throughout South America, polyploid species are clustered by the Southeastern coast between 40-10oS. This region covers much of the Atlantic forest and shares considerable overlap with the South American dry diagonal. These biomes are hypothesized to have played important roles in maintaining biodiversity over evolutionary time, in addition to being modern day biodiversity "hot-spots". We also recover some evidence to suggest the observed trend may be the result of more recent anthropogenic influences. Polyploids are positively correlated with areas of high pollution from agricultural runoff, whereas diploids are negatively correlated. Similarly, polyploids are more likely than diploids to occur in areas of high human impact such as croplands, pastures, and urbanized environments. Exploring genomic data from these genera may further elucidate evolutionary dynamics between diploids and polyploids and unlock the secrets of polyploid genomes.

122-6 DAVIS, AL*; NIJHOUT, HF; JOHNSEN, S; Duke University; *al.davis@duke.edu*

Convergent evolution of ultra-black butterfly scales

Understanding animal coloration is important for investigating sexual selection, speciation, and animal signaling. Despite a growing number of papers investigating structural colors, the role of nanostructures in creating black color patches has largely been ignored. Recently, it has been shown that certain animals have evolved micro- or nano-structures responsible for creating matte-black surfaces with reflectances approaching the darkest synthetic materials. It has been shown that certain papilionid butterflies reflect as little as 0.2% of incident light, and this phenomenon is mediated by a honeycomb scale structure with melanin bound to the cuticle. It is unknown, however, if other ultra-black butterflies use this mechanism and whether we can derive general principles about the design of ultra-black materials from butterfly scales. We examined butterflies from four subfamilies and demonstrate that ultra-black color can be achieved through various scale geometries from honeycombs to rectangular holes. Using scanning electron microscopy, we found considerable interspecific variation in the geometry of the holes that does not mirror differences in reflectance. Furthermore, we verified with finite-difference time-domain modeling that the two structural features found consistently in ultra-black scales – steep ridges and expanded trabeculae – each reduce reflectance by up to 16-fold compared to scales lacking these features. Our results demonstrate that butterflies have convergently evolved ultra-black scales by creating a material with high internal surface area that minimizes surface reflection and increases the opportunity for absorption. We hypothesize that butterflies use these ultra-black wing patches to increase the perceived brightness of color signals for use in intra- and interspecific signals

109-3 DAVIS, RL*; CRISTOL, DA; HEIDINGER, BJ; KITTILSON, J; SWADDLE, JP; William & Mary, North Dakota State University , North Dakota State University ; *rldavis@email.wm.edu*

Does lifetime methylmercury exposure impact telomere length in various organs within the zebra finch?

Methylmercury (MeHg) is a highly toxic global pollutant that affects human, wildlife, and ecosystem health. This heavy metal compound can successfully cross the blood brain barrier and is capable of inducing oxidative stress in the formation of free radicals. Organs such as the liver and kidney, which play large roles in the excretory system, may be overwhelmed by the cellular damage caused by exposure to MeHg due to their functional role. Further understanding of how MeHg exposure alters organ performance at a cellular level is critical to understanding physiological effects this toxin can have on both humans and wildlife impacted by environmental contamination. Telomere length is a recently popularized biomarker of biological aging and cellular damage, influenced by both genetics and environment. To assess the impact of MeHg on eukaryotic organisms, we studied how lifetime exposure to dietary MeHg impacts telomere length in various tissues of the zebra finch (*Taeniopygia guttata*) at four time points after hatching from eggs. Using qPCR, we measured relative telomere lengths of brain, liver, kidney, heart, and red blood cells. We predicted that telomere length would decrease with the age of birds, and individuals exposed to an environmentally relevant level of dietary MeHg would have reduced telomere lengths compared to controls. Although blood telomere length clearly declined with age as predicted, we found that mercury-exposed birds had consistently longer telomere lengths in virtually all tissues and time points relative to controls. This latter result suggests the potential selection for longer telomeres within embryos (before egg hatching) and/or disruption of the telomerase pathway by MeHg.

127-4 DAVIS-BERG, EC*; WILSON, BA; ARNOLD, C; ALMARIO-KOPP, D; Columbia College Chicago, Chicago, IL, Liberty Public Schools, Liberty, KS, Prairie State College, Chicago Heights, IL; *edavisberg@colum.edu*

Molluscs of Anderson County Prairies, a native tallgrass prairie in Eastern Kansas

Tallgrass prairies are plant and animal communities which once covered much of the United States. Anderson County Prairies (1450 acres) are located near Welda, KS; have very deep soils and higher rainfall than other prairies found further west in the state. The goal for this preserve is to maintain and enhance native biodiversity within an imperiled tallgrass prairie ecosystem. It has populations of the threatened plant, Mead's Milkweed and is owned by the Nature Conservancy. Here we present results of our periodic surveys since 2004 at Anderson County Prairies. These preserves consist of native tallgrass prairie with some plots which have been and are currently used for cattle pasture. We have found differences in gastropod diversity by land use with higher counts and different species at the non-pastured versus the pastured land. We combined soil analyses with the gastropod data to determine the source of these patterns.

S9-9 DE MEYER, J.*; VERHELST, P.; ADRIAENS, D.; University of Ghent; *jendmeye.demeyer@ugent.be*

The role of understanding the eel's morphology in stopping its decline

The European eel (*Anguilla anguilla*) is a critically endangered species, whose recruitment stocks have declined to nearly 1% compared to the late 70's. An amalgam of factors are responsible for this, amongst them climate change, migration barriers and habitat loss, pollution, non-native parasites and overfishing. While most studies related to eel conservation focus on these aspects, little attention is given to the eel's morphology in function of management measures. Worryingly, however, less than 50% of the currently installed management plans reach their goals, strongly indicating that more information is needed about the eel's morphology, ecology and behavior. In a series of studies, we evaluated how the eel's morphology is related to several ecological and behavioral factors, which provides new insights to install proper management plans. First, we showed that the eel's head shape is related to diet, with broader-headed eels being on a higher trophic level than narrow-headed eels. This difference in trophic position subsequently results in pollutant uptake variability: The higher an eel's position in the food chain, the more pollutants it will accumulate. This link between morphology, ecology and pollution highlights that pollution can affect eels differently. In another study, we evaluated whether broad- and narrow-headed eels differ in migration behavior. Finally, we evaluated burrowing behavior of the European eel and substrate preference. This latter study showed that eels may also suffer from hypoxia and sediment pollution and provides novel insights in how anthropogenic actions such as dredging and extraction of sand and gravel can impact the eel's behavior. The link between an eel's morphology, behavior and ecology therefore plays a pivotal role in maintaining the European eel population.

110-5 DEAN, MN*; BLUMER, M; GUALDA, E; CHAUMEL, J; SEIDEL, R; MARSAL, M; OMELON, S; MPIKG;
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Cartilage canals in ray skeletons: Morphology, homology and putative role in mineralization
Although cartilage is typically described as avascular, this is not always true. In developing mammal/bird skeletons, particularly regions of endochondral ossification, hyaline cartilage is invested by a dense network of tubules called cartilage canals. These canals carry vasculature and undifferentiated mesenchymal cells, are lined by Type I collagen, nourish cartilage, and develop ossification centers. The canals and their vascular network are typically obliterated as animals age. We use a range of tissue characterization/visualization techniques to show that cartilaginous fishes (rays and relatives) possess cartilage canals which persist throughout life. Elasmobranch skeletons are comprised largely of a hyaline-like cartilage sheathed in mineralized geometric tiles (tesserae). Cartilage canals were observed in species from disparate groups, starting in the outer fibrous perichondrium, perforating the tesserae layer in large circular pores, and penetrating the uncalcified cartilage. As in other vertebrates, canals carried vasculature, were either unbranched or bifurcated blunt tubules, but never extended completely through skeletal elements. We demonstrate that Type I collagen lines canals, the same lining canals and forming the perichondrium in mammals/birds. Fluorescence microscopy of DAPI-stained samples suggests canals contain polyphosphates, stable apatite nucleation precursors for controlled distribution to mineralization sites. The morphology and tissue composition of elasmobranch cartilage canals argues for homology with mammal/bird canals and an ancient invasion of bone-like collagen (Type I) into cartilage (Type II collagen). However, anatomical location —heading from mineralized tissue not toward it— and the lack of endochondral ossification in elasmobranch cartilage points to alternative roles for these canals in more basal vertebrate skeletal types.

41-1 DEARBORN, DC*; WARREN, S; HAILER, F; Bates College, Lewiston, Maine and Cardiff University, Cardiff, UK, Bates College, Lewiston, Maine, Cardiff University, Cardiff, UK;
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Meta-analysis of Diversity and Selection at MHC Class II A Genes: the Neglected Half of the Vertebrate Immune System's Heterodimer
Genes of the vertebrate Major Histocompatibility Complex (MHC) defend against disease by making cell-surface proteins that display pathogen peptides to the immune system. Class II MHC proteins are heterodimers encoded by two different genes, but most studies of natural selection or sexual selection have focused only on the II B genes which encode the beta subunit. Here, we characterize MHC Class II A genes in Leach's storm-petrels and then synthesize data across vertebrate species to examine the evolutionary dynamics of these understudied II A genes. Leach's storm-petrels fit the dogma that II A genes are oligomorphic, but our meta-analysis shows that several other species have more than 40 II A alleles within a single population. In many species, allelic polymorphism was similar between II A and II B genes. Less surprisingly, the number of alleles found per species was positively related to sampling effort. However, there was an additional effect of taxonomic group, with fish having more alleles per species than mammals. We found no support for the hypothesis that gene duplication and proliferation of allelic diversity are negatively correlated, that is, that they could be alternative routes to generating a consistently high level of functional diversity in the alpha subunit of the protein. Analyses are in progress to compare signatures of selection at these two groups of genes, to test the hypothesis that II A should show more purifying selection in comparison to the common finding of diversifying selection at II B. Overall results will help determine whether studies of pathogen-mediated selection should continue to neglect the alpha subunit of the protein.

1-5 DEANGELIS, R/S*; RHODES, J/S; University of Texas, University of Illinois; *Ross.DeAngelis@gmail.com*
Nonapeptides Mediate Trade-Offs in Parental Care Strategy
Parental care represents a suite of distinct behaviors performed by parents to maximize fitness. Dynamic shifts in parental care strategies, such as between nest defense and direct provisioning of the offspring, are required in response to environmental variation. However, the neural mechanisms that mediate strategic parental decisions remain unknown. The anemonefish, Amphiprion ocellaris represents a burgeoning model in social neuroscience which is conducive to manipulating the environment while simultaneously measuring nest defense and direct egg provisioning. The goal of this study was to determine the extent to which arginine vasotocin (AVT) and isotocin (IT) signaling mediate decisions in parental care strategy. Specifically, we tested the hypotheses that AVT signaling is critical for aggressive egg defense and that IT signaling is critical for direct egg attendance. Blockade of IT, using an IT receptor antagonist, significantly reduced direct egg attendance, and increased levels of aggressive egg defense. Conversely, blockade of AVT reduced aggression and tended to increase egg care. Results demonstrate that male anemonefish alter their parental strategy with increased predation risk, and that IT and AVT signaling pathways are important neural substrates underlying decisional trade-offs, weighing heightened aggression against reduced egg attendance.

61-5 DEARING, MD; University of Utah, Salt Lake City, Utah ;
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Mechanisms of detoxification in herbivorous mammals
Herbivores are confronted with potentially toxic diets at every meal, and therefore, must employ physiological, microbial or behavioral processes to circumvent dietary toxicity. This presentation reviews our physiological and behavioral work on this topic with a focus on the results from our studies on herbivorous rodents (and species). With respect to physiological mechanisms related to dietary specialization on toxic diets, we have 1) identified patterns in particular biotransformation ("detoxification") enzymes and quantified the energetic costs of some of these enzymes, 2) correlated gene copy number with dietary specialization, and 3) identified and characterized, at the molecular level, several novel P450s of importance. We are currently undertaking a genome resequencing approach to identify the physiological mechanisms that enable ingestion of toxic diets. On the behavioral front, we have documented unique feeding behaviors used by rodents to circumvent complex toxins in fruits. This work, which had its origins in the research group of Dr. William Karasov, advances our understanding of the mechanisms used by herbivorous mammals to deal with toxic diets.

S5-5 DEBAN, SM*; HOLZMAN, R; MULLER, UK; University of South Florida, Tel Aviv University, California State University Fresno; *umuller@csufresno.edu*

Suction feeding in small animals and carnivorous plants

Suction feeding has evolved independently in two highly disparate systems, aquatic vertebrates and carnivorous bladderworts. Incidentally, bladderworts are the smallest and fastest known suction feeders. Body size has profound effects on aquatic organismal function, including suction feeding. Surprisingly, plant suction feeders appear to have a lower size limit than animal suction feeders. We review how organisms' solutions to functional challenges is affected by their energy budget. Suction feeding at small size takes enormous energy investment, and as a consequence a minority of tiny organisms can afford to suction feed while most cannot. We address two hypotheses that emerge from this core idea: (1) autotrophic organisms (plants) can afford to pay the price that suction feeding requires because they obtain energy through photosynthesis and feed only for nutrients, and (2) heterotrophic organisms (animals) may not be able to suction feed at a comparable scale as plants due to the energetic costs, and furthermore, may be able to feed at the small end of their size range only by employing supplementary mechanisms such as ram and mouth protrusion. Here we review current knowledge of suction feeding to explore energetic and biomechanical performance limits for aquatic feeders based on morphology and kinematics. The performance outcomes of the complex interplay of size, energetics, and biomechanics can be used to produce a causal, predictive framework for suction feeders that is generalizable beyond the focal organisms.

20-2 DELCLOS, PJ*; MEISEL, RP; University of Houston; *pdelclos@uh.edu*

Genotype-by-temperature effects on thermal preference in the house fly Musca domestica

Environmental temperature strongly affects the physiology of individuals, and so thermoregulation is vital for maximizing an individual's fitness. Ectotherms largely rely on two mechanisms to thermoregulate: while many ectotherms have a limited ability to ameliorate the effects of extreme temperature physiologically, many can behaviorally thermoregulate by moving to more ideal temperatures. As such, habitat use and behavioral patterns can be largely affected by thermal preference functions, and we can expect the development of thermal preferences to be dependent on a variety of genetic and environmental factors. For instance, biogeographical patterns among or within species can be expected to shape individual thermal preferences, allowing for avoidance of extreme temperatures or maximizing time spent at physiologically optimal ones. The house fly *Musca domestica* is an ideal system to examine how genotype and environment interact to shape thermal preferences. In replicated natural systems, we observe a latitudinal cline varying in the male-determining Y chromosome. Specifically, males from cooler, northern populations carry the male-determining gene on the Y chromosome, whereas those from warmer, southern populations carry the gene on the third chromosome. Here, we tested whether chromosomal location of the male-determining gene and rearing temperature affected both mean thermal preference and the breadth of thermal preference, measured as the coefficient of variation of individual-level thermal preference. The results obtained from this study will help elucidate the mechanisms shaping the observed latitudinal cline within *M. domestica*, as well as provide a greater understanding of how genotype and the environment interact to shape the development of physiologically relevant behaviors.

64-7 DeLeo, DM*; Bracken-Grissom, HD; Florida International University, Miami, FL; *dmdeleo14@gmail.com*

The Largest Migration on Earth: Sensory Adaptations of a Bioluminescent Deep-sea Vertical Migrator

Diel vertical migration of deep-sea animals represents the largest migration on our planet. Vertically migrating fauna are subjected to a variety of light fields among other environmental conditions that can have notable impacts on sensory mechanisms, including an organism's visual capabilities. Among deep-sea migrators are oplophorid shrimp, that vertically migrate 100s of meters (m) to feed in shallow waters at night. These species also have bioluminescent light organs called photophores that emit light during shallow-water migrations to aid in a dynamic form of camouflage known as counterillumination. The organs have recently been shown to contain opsins and other genes that infer light sensitivity. Knowledge regarding the impacts of this vertical migratory behavior, and fluctuating environmental conditions, on sensory system (visual/photophore) evolution is unknown. In this study, the oplophorid *Systellaspis debilis* was either collected pre-sunset (Day) from 450-750 m, or pre-dawn (Night) from 150-330 m to ensure sampling across the vertical distributional range. RNA was then extracted and sequenced from the light sensitive tissues (eyes/photophores). *De novo* transcriptomes were assembled discretely for each tissue from *Day* (n=5) and *Night* (n=5) specimens and analyzed to characterize opsin diversity, visual and light interaction genes within a phylogenetic context. Gene expression analyses were also conducted to quantify expression differences associated with the migration. This study sheds light on the visual system of a deep-sea bioluminescent shrimp and provides additional evidence for photophore light sensitivity. Our findings also suggest opsin coexpression and subsequent fluctuations in opsin expression may play an important role in diversifying the visual responses of this deep-sea vertical migrator.

103-7 DEORA, T*; BRUNTON, BW; AHMED, M; DANIEL, TL; University of Washington, Seattle, WA; *tanvid2@uw.edu*

Tactile active sensing and learning in plant-insect pollination

Sensory systems play a crucial role in the interaction between plants and their insect pollinators. The plants' visual and olfactory cues determine how insects navigate to flowers. As they approach flowers, moths unfurl their proboscis -- straw-like mouthparts that provide mechanosensory feedback as an additional sensory modality to localize and feed from the tiny nectary. Finding the tiny nectary is a challenging task, especially for crepuscular moths that hover over flowers while they feed in low light conditions. Despite the ecological importance of this behavior, few studies have focused on the role of tactile feedback in floral exploration. To examine the role of mechanosensory input, we developed an assay to track naive hawkmoths, *Manduca sexta* , as they fed from 3D-printed artificial flowers with different curvatures. Their geometry varied from naturally occurring trumpet-shaped flowers that are easy to exploit to completely flat flowers that are more challenging. We found that moths became increasingly efficient at locating the nectary over just a few visits, even on flowers that have only slight curvature. Using computer vision and machine learning methods, we tracked the proboscis as moths explored flower surfaces. We found that they repeatedly swept their proboscis across the flower surface in a manner reminiscent of rat whisking. In particular, they whisk along the radial direction of the flower, varying the angle of whisk as they explore the curvature of the flower. The number of whisks decreases as the moths learn to handle floral shapes. However, the number of whisks remains high for flat floral shapes. Our results show that moths use tactile sensing to actively explore flower surfaces and rapidly learn to handle novel flowers, enabling pollination.

93-5 DESIMONE, JG*; TOBALSKE, BW; BREUNER, CW; University of Montana, Missoula; *joely.desimone@umontana.edu*
Prepare or Escape?: The Behavioral, Physiological, and Hormonal Responses of a Facultative Migrant to Declining Food Availability
Migration is an evolved behavior that allows animals to take advantage of resources that are variable in time and/or space, and different migratory strategies depend on the predictability of resource variation. When food varies seasonally, obligate migrants can anticipate and prepare for migration, but it is unknown whether facultative migrants, whose movements are characteristically unpredictable in timing and destination, prepare for migration or rather escape when resources are low. Here we conducted a captive experiment to test two hypotheses about the behavioral and hormonal responses of a facultative migrant (Pine siskin; Spinus pinus) to declining food availability. Prepare Hypothesis: Siskins prepare for departure by increasing fuel stores, and elevations of baseline corticosterone (CORT) support increased locomotor activity. Escape Hypothesis: Siskins don't prepare for departure, body condition declines as food availability declines, and stress-related levels of CORT induce escape behavior. Throughout a 15-day experiment, we measured body composition using a Quantitative Magnetic Resonance machine, continuous locomotor activity using force perches, and baseline CORT levels among birds given ad libitum food or a slow decline, fast decline, or randomly changing amount of food. We found support for the Escape Hypothesis. Siskins' body condition declined as food declined, baseline CORT was elevated in birds with reduced lean mass, and birds showed marked increases in activity only when food availability was low. This work shows that facultative movements are physiologically distinct from seasonal, obligate migration, with food availability likely serving as a proximate cue, and birds showing little to no preparation for flight.

4-1 DIAL, TR*; LAUDER, GV; Harvard University; *trdial@gmail.com*
Longer Development Provides First-Feeding Fish with the Jaw Kinematics to Escape Hydrodynamic Constraints
The viscous fluid environment experienced by small, first-feeding fishes resists the ability to produce suction. Compounding the negative effects of small size is the observation that larval fish are inherently immature – first relying on exogenous food sources at as soon as 5 days post fertilization (dpf). Here we compare first-feeding performance, kinematics and hydrodynamics of two species of freshwater fishes (zebrafish and guppy) that produce offspring at 5 $\pm$ 0.5 mm in length, but that undergo a 5-fold difference in developmental time (5 vs. 25 dpf, respectively). By manipulating water viscosity, we control the hydrodynamic regime, measured as Reynolds number (Re). Despite first-feeding occurring at similar levels of maturity for both species, capture success is significantly higher in guppies (90% vs. 20%). At any given Re, guppies successfully feed at five-times greater distances to prey (1.0 vs. 0.2 mm). Flow visualization reveals a bow wave is produced ahead of each approaching fish (zebrafish larvae ~ 0.2 mm; guppy offspring ~ 0.4 mm), limiting the predator's proximity to prey. During suction, zebrafish larvae generate flow fields that extend up to, but not beyond, the bow wave. Guppy offspring, likely due to their capacity to protrude the oral jaws, generate a suction field that extends well beyond the horizon of the bow wave, thus leading to successful prey capture from much greater distances. We argue that the difference in observed suction performance, having experimentally controlled for issues of scale, can be best explained by the degree of maturation achieved at the time of first-feeding.

50-8 DIAMOND, KM*; GRINER, JG; LAGARDE, R; PONTON, D; POWDER, KE; SCHOENFUSS, HL; WALKER, JA; BLOB, RW; Clemson Univ., Univ. Perpignan Via Domitia, Univ. La Réunion, St. Cloud State Univ., Univ. Southern Maine; *kmdiamo@g.clemson.edu*
Linking morphology, performance, and behavior in the migration of stream goby fishes
Many animals migrate between habitats during their lifetime, encountering challenges to survival along the way. How do performance and body shape of animals help them to overcome the challenges of moving to a new habitat? To study which traits aid in migration, we examined a group of goby fishes that migrate from the ocean where young fish develop, to freshwater streams where fish live as adults. As fish migrate, they must overcome fast stream flows and piscivorous predators. Some species also ascend waterfalls to reach upstream habitats. We measured variation in performance and body shape across six species and two life stages to address two main questions. First, is there a point during migration when the strongest performing fish tend to move upstream? For this study, we collected climbing and escape response data from fishes throughout migrations. Climbing performance peaks 3-5 days after a migration begins, whereas escape performance remains constant throughout a migration. Second, can the predator regime to which fish are exposed influence the performance and/or body shape of fishes that survive to adulthood? We found that fishes living in regimes of consistent predation through their life cycle had low accelerations, but tall bodies, which may gape-limit their predators. Gobies that migrate to habitats with diminished predation showed the highest accelerations, as well as elongated posterior body shapes that may aid in producing higher thrust compared to fishes that live in predator-free habitats. These two analyses show how both morphology and performance relate to migratory behavior in fishes, potentially aiding management decisions for these taxa.

134-1 DIAZ, C*; TANIKAWA, A; LONG, JH; Vassar College, Poughkeepsie, NY, The University of Tokyo, Tokyo, JAPAN; *candido.diaz.jr@gmail.com*
Some Spider Glue is Super: Modeling the Fast Spreading Bioadhesive That Defeats the Scale Shedding Defense of Moths
Common orb weaving spiders don't catch many moths. Moths evade capture by shedding the scales on their body and wings when those microstructures contact adhesive on the web. Orb weavers of the genus *Cyrtarachne* have evolved a solution that allows them to be moth-catching specialists: a low-viscosity glue that flows quickly under the moth's scales, gluing the scales and the web attached to them to the underlying cuticle before the scales can be shed. The glue from one species, *Cyrtarachne akirai*, is unremarkable when its properties are measured on glass, the classic substrate for bioadhesion test, but when this glue is tested on biomimetic substrates made from scaled moth wings, its behavior changes dramatically, spreading three times farther and required eight times the force to remove. We hypothesize that this 'hyper-wetting' is caused by the interaction of the glue and the topology of the scales. Using the physics of droplets, capillary forces, and pipe flow, we propose several spreading models. The models are tested and compared using the spreading behavior measured in the experimental situation. We propose that the glue of *Cyrtarachne* is of a particular viscosity that interacts with the scales favorably, creating a porous material, wicking water using capillary action. We tested this by comparing the spreading behavior of (1) variable viscosity liquids brought into contact with scaled surfaces and (2) glue droplets spread on surfaces of various porosities. Furthermore, our model predicts this 'hyper-wetting' leads to a separation of the water soluble components and glycoproteins within the droplet, leading to glue hardening. We used Raman spectroscopy to test this by measuring the distribution of salts and proteins along the radius of droplets spread on glass and moth wings.

60-7 DIAZ, K*; WANG, T; CHONG, B; DING, JL; LU, H; SARTORETTI, G; CHOSET, H; GOLDMAN, DI; Georgia Tech, Carnegie Mellon; *kelimar.diaz@gatech.edu*
Steering Behaviors of C. elegans Locomotion in Heterogeneous Environments
To successfully traverse dissipative environments, slithering animals (e.g., snakes, nematodes) must generate appropriate reaction forces to overcome friction. In yielding substrates (e.g., sand) where there is permanent deformation post interaction, maneuverability is essential in order to overcome heterogeneities. In particular, the mm-long nematode worm *C. elegans* is able to traverse complex environments by using complex steering behaviors without being hindered by heterogeneities. While this worm is the subject of thousands of studies, few have focused on how it performs and controls self-propulsion. To discover principles of nematode control and steering, we conducted experiments in fluid-filled PDMS lattice of posts. We induced escape responses in the lattices via localized thermal stimuli to *C. elegans* with a NIR laser diode (Mohammadi et al, 2013). When stimulated in the head, worms respond by escaping from the thermal source via backing up, self-deforming the body to an omega-like shape for reorientation (known as an omega turn) and moving forward, previously studied in detail in homogeneous environments. This was surprising as we expected omega turns in the lattice to be hindered by obstacles. However, performance was comparable to that on the surface of homogeneous agar plates. A geometric mechanics framework rationalized the observed biological turn dynamics. We posit omega turns are a robust way to turn and maneuver in complex environments. Inspired by the worms capabilities in heterogeneous environments, we developed a robot controller to enable maneuvering in lattices via a scheme which senses joint torques to enable shape-based compliance control.

77-5 DICHIERA, AM*; ESBAUGH, AJ; The University of Texas at Austin, Marine Science Institute; *angelina.dichiera@utexas.edu*
Red blood cell carbonic anhydrase dictates oxygen delivery rate in red drum (Sciaenops ocellatus)
In many teleosts, oxygen (O_2) and carbon dioxide (CO_2) transport are tightly coupled due to the presence of Root effect hemoglobin (Hb), whereby reduced pH dramatically reduces binding affinity and capacity for O_2. Previous work demonstrates that the evolution of Root effect Hb in teleosts coincided with the incorporation of high-activity carbonic anhydrase into the red blood cell (RBC CA). In most vertebrates, the role of RBC CA is thought to be exclusively related to CO_2 transport and excretion, as it is responsible for catalyzing the reversible dehydration/hydration reactions of CO_2. However, RBC CA also dictates the rate of red blood cell acidification during capillary transport, which impacts the relationship between Hb and O_2. Thus, high-activity RBC CA may be an important, previously unknown component of enhanced tissue O_2 delivery in teleosts that contain Root effect Hb. We have developed an *in vitro* assay using lysed red blood cells that allows us to manipulate RBC CA activity while simultaneously measuring O_2 offloading following CO_2 injection. 50% RBC CA inhibition significantly decreased oxygen delivery rate ($p = 0.0196$, Student's t-test) by 50%, demonstrating an almost 1:1 relationship between RBC CA activity and oxygen delivery rate. Additionally, we found that across a ten-fold range in body mass, the allometric scaling of RBC CA activity demonstrates a relationship much like that of standard and maximum metabolic rate. This suggests individuals with higher oxygen demands have higher RBC CA activity. Combined, our data suggest RBC CA dictates O_2 delivery in conjunction with its characteristic role in CO_2 excretion, expanding its function in respiratory gas exchange for the first time in almost 90 years.

18-8 DIEZ, A; MACDOUGALL-SHACKLETON, SA*; University of Western Ontario; *smacdou2@uwo.ca*
Neurogenesis and the development of neural sex differences in vocal control regions of songbirds
The brain regions that control the learning and production in birdsong exhibit some of the larges sex differences in the brain known in vertebrates, and are associated with sex differences in singing behaviour. Song learning takes place through multiple stages: an early sensory phase when song models are memorized, followed by a sensorimotor phase in which auditory feedback is used to modify song output through subsong, plastic song, to adult crystalized song. However, how patterns of neural development in the caudal motor path and anterior forebrain path change through these learning stages, and differ between the sexes, is little explored. We collected brains from 76 young male and female zebra finches *Taeniopygia guttata* over 4 stages of song learning. Using neurogenesis markers for cell division (PCNA), neuron migration (doublecortin), and mature neurons (NeuN) we demonstrate that there are sex-specific changes in neurogenesis over song development that differ between the two pathways of the vocal control circuit. The emergence of neural sex differences in this system thus emerge gradually and with specific trajectories depending on the brain region and its function.

33-7 DIJKSTRA, PD*; FIALKOWSKI, RJ; JANESKI, HM; AUFDEMBERGE, PM; Central Michigan University, Department of Biology, Mt. Pleasant, MI; *dijks1p@cmich.edu*
Sexual Selection Favors Phenotypic Plasticity in Body Coloration in a Polymorphic Cichlid Fish
Sexual selection by female mate choice is a major driving force in speciation. Since sexually selected male traits are often plastic, phenotypic plasticity and sexual selection are thought to jointly facilitate diversification when initially plastic sexual traits undergo genetic divergence by sexual selection. However, sexual selection may also promote plasticity. The resulting increased plasticity can then shield populations from the effects of selection, thereby inhibiting genetic divergence. We show that a combination of mate choice and male-male competition can maintain extreme phenotypic plasticity in a sexually selected male trait. In the cichlid species *Astatotilapia burtoni*, males are either blue or yellow. We show that adult males frequently change between yellow and blue color with blue males showing more color plasticity than yellow males. We then show that this remarkable plasticity in male color is directly influenced by the social environment: more males express yellow coloration in environments with more intense male-male competition. In staged combats, yellow males are more successful competitors than blue males, which could explain the higher proportion of yellow morphs in more competitive environments. However, females express a strong sexual preference for blue males. The trade-off between different components of sexual selection could promote the persistence of plastic coloration. Our work suggests that sexual selection may maintain phenotypic plasticity and potentially inhibit genetic diversification in sexually selected traits.

66-2 DILLON, ME*; PETRANEK, C; University of Wyoming; *Michael.Dillon@uwyo.edu*

Induced flow cools hovering bumble bees

The advent of flight likely facilitated insect dominance of the terrestrial biosphere. In particular, rapid wing oscillations made possible by asynchronous flight muscle allow small insects to hover and maneuver in nearly all habitats on earth. To keep an insect aloft, the flapping wings must produce a sufficiently strong downward draft of air to offset body weight; with this induced flow comes induced power, a major component of aerodynamic power required for flight. Although developments in technology and theory have facilitated rapid advances in our understanding of how insects meet the aerodynamic and energetic demands of flight, the thermal consequences of exposure to a swiftly moving self-generated column of air have received little attention. To better understand the role of induced flow in heat loss for flying insects, we focused on bumblebees, which must maintain high body temperatures to maintain flight necessary for feeding from flowers, and which have relatively high flapping frequencies (and therefore induced flows) to offset their large body size. We measured induced flows and associated wingbeat kinematics for bumblebees of different sizes hovering in free flight in front of artificial flowers. We then measured rates of heat loss from bumblebee models when exposed air streams of the same velocity and basic structure as those measured. As expected, induced flows depended strongly on body mass and wingtip velocity, ranging from 0.2 to nearly 2 m/s. These induced flows resulted in rapid cooling of non-metabolizing bumble bees: a heat balance model suggests that ignoring induced flow underestimates heat loss, leading to erroneous predictions of rapid overheating of hovering bumblebees. These findings likely apply broadly to hovering insects, with the effects of induced flow on heat balance predictably varying with wing kinematics and body size.

24-4 DIMOS, BA*; MACKNIGHT, NJ; BRANDT, M; MYDLARZ, LD; University of Texas at Arlington, University of the Virgin Islands; *bradford.dimos@uta.edu*

Differential Disease Susceptibility Between Closely Related Coral Species is due to Regulation of Mitochondrial Genes

Marine diseases affecting reef building corals have radically transformed Caribbean reef ecosystems where disease-resistant species are favored to persist. In order to respond to pathogenic microbes, corals possess a well-stocked innate immune arsenal, and recent evidence indicates that like model organisms their innate immune system is regulated in large part by mitochondrial function. To investigate inter-species disease resistance mechanisms, we conducted a disease transmission experiment of the coral disease White Plague (WP) between two closely related species of coral: *Orbicella faveolata*, and *Montastrea cavernosa*. We found that *O. faveolata* is highly susceptible to this disease while *M. cavernosa* appears to be completely resistant in a laboratory setting. By using a comparative transcriptomics approach, we find a set of genes that are differentially expressed during disease exposure in both species. This analysis highlights a largely conserved response to disease including oxidative bursts and mitochondrial dysfunction. By applying a network-based gene expression analysis we also identify sets of genes with species-biased expression patterns which indicate differential regulation of mitochondrial genes. Additionally, pathway level analysis shows that these species activate and repress alternate pathways and regulatory molecules when challenge with White Plague. Overall, this investigation indicates that differential regulation of mitochondrial processes and subsequent employment of alternative cellular pathways during disease exposure may underlie the divergent disease resistance phenotypes between these two species.

63-6 DINH, JP*; AZZA, J; PATEK, SN; Biology Department, Duke University; *jpd29@duke.edu*

Assessing Your Opponent: Snapping Shrimp Use Indirect Cues to Settle Ritualized Contests

Animal contests occur over indivisible resources. On average, winners have higher resource holding potential (RHP), which is a composite measure encompassing variables like size, physiological state, and skill. During mutual assessment, animals estimate the relative RHP of their opponent to decide when to leave contests. However, the cognitive mechanisms underlying mutual assessment are unknown. One possibility is that animals indirectly assess RHP by assessing a correlated but more accessible attribute - the heuristic attribute. Using a heuristic allows animals to make fast decisions with readily available information. Here, we show that snapping shrimp conduct mutual assessment using a heuristic based on recent contest success. In snapping shrimp, recent contest winners signify recent success through a chemical signal. We hypothesized that snapping shrimp use this signal as a heuristic attribute for RHP. To test our hypothesis, we collected 52 snapping shrimp from Beaufort, SC. We tested predictions made by different assessment types by staging 26 randomly matched contests and 24 RHP-matched contests. Then, we tested if snapping shrimp use a heuristic based on recent contest success by staging an additional 24 contests between individuals with recent contest experience - 12 between small recent winners and large recent losers and 12 between large recent winners and small recent losers. We found that snapping shrimp settle contests using mutual assessment and a heuristic based on recent contest success. This minimizes the energetic costs and risk of injury associated with gathering reliable information. Similar heuristic-based decision rules might be widespread across animals and behaviors because they facilitate quick decisions while minimizing costs.

107-2 DIXON, G*; MATZ, MV; University of Texas at Austin; *grovesdixon@gmail.com*

Three-way genomic characterization (molecular evolution, gene expression, and DNA methylation) of the key morphological Innovation of the coral genus Acropora

The role of DNA methylation in invertebrate gene regulation, if any, remains uncertain. We examine this question using axial and radial polyps of the coral *Acropora millepora* as a model for gene regulation. These dimorphic polyp types represent a key innovation of the *Acropora* genus, giving it uniquely rapid growth rates and morphological diversity. We compare gene expression and DNA methylation between these two polyp types from two colonies, assaying gene expression using Tag-seq, and DNA methylation using three different methods: whole genome bisulfite sequencing (WGBS), Methylation binding domain sequencing (MBD-seq), and methylation-selective restriction enzymes (MethylRAD). We begin by benchmarking the three methylomic assays, showing that they provide similar readouts of DNA methylation. We then examine the covariation between methylation and transcription, both between polyp types and coral colonies. Finally, we take a molecular evolutionary approach to identify genes under positive selection in the lineage preceding *Acropora* diversification. We compare these genes with those showing differential expression and methylation between polyp types to identify candidate genes involved in the evolution of polyp dimorphism key innovation.

32-2 DOLAN, JE*; MUSIAL, NA; HAMMOND, KA; UC, Riverside; *jdola001@ucr.edu*

Energy expenditure of cage activity versus wheel running in deer mice

In the lab, mice are often kept in cages seemingly without any way to exercise, thus restricting their voluntary energy expenditure. Because of this their daily energy expenditure in a cage may grossly underestimate the amount of energy they would expend in the wild. We have been interested in understanding how much energy mice would expend if they could be more active in cages. In recent laboratory experiments we have included wheel access for the deer mice to allow them to have that voluntary component. However, deer mice in cages without wheels often jump up and down and do backflips in their cages. The energy exerted in these behaviors, is non measurable and could be equal to that of wheel running. In order to determine if this is the case, daily oxygen consumption (as a proxy for daily energy expenditure) was measured in mice without and then with wheels. In addition, food intake was measured in each mouse before and after they were given wheels. Measurement without wheel access was always done first because introduction of a wheel could affect future activity. Mass did not differ between treatments and was not a significant covariate for statistical tests. Using age as a covariate, an ANCOVA showed that mice with wheels ate 15% more food that those without wheels ($p = 0.008$; Age was significant at $p = 0.025$). Likewise mice with wheels expended 34% more energy than those without wheels ($p=0.0002$). Also, the average maximal 10 minutes of oxygen consumption was higher in mice with wheel access ($p=0.006$) and the minimal 10 minutes of oxygen consumption was higher in mice with wheels ($p=0.020$). In conclusion, this study suggests that mice can expend more energy if given access to a wheel. The back flips and jumping that occurs in the cage overall leads to less energy expended. Inclusion of a wheel should be considered in future experiments with the goal of testing the limits of energy expenditure.

39-1 DOLPHIN, KE*; FISCHER, EK; HUGHES, KA; HOKE, KL; Colorado State University, Stanford University, Florida State University; *kedolphin@gmail.com*

What in your right mind would make you do that!? Identifying neural components of courtship decisions

Animals can adjust mating strategies flexibly by integrating information about acute contexts. To understand constraints on animal decision making, we are characterizing mechanisms by which external sensory and internal physiological cues guide behaviors. We attempted to open the black box of mechanisms controlling behavioral flexibility by identifying neurons activated while male Trinidadian guppies (*Poecilia reticulata*) rapidly decide between two mating tactics. We used a selective RNA-seq method to compare transcripts expressed in recently activated neurons in males exposed to reproductive and asocial contexts. Our results characterize transcripts that vary in expression when males decide between alternative mating tactics. Follow-up experiments will analyze region-specific expression to identify the neural substrates of reproductive decisions.

128-6 DORNHAUS, A*; KELEMEN, EP; RIVERA, MD; University of Arizona, York University, University of Illinois at Urbana-Champaign; *dornhaus@email.arizona.edu*

Designed for Comparative Advantage: Body size, Division of Labor, and the Benefits of Worse Workers in Bumble Bees

In many complex systems, individual units show diversity in form and function. Often this is in the service of division of labor, such that specialized units perform particularly well in their tasks; in other cases, variation among individuals seems like random noise. Here we introduce another group-level benefit of diversity coupled with division of labor, based on the trade-off between unit costs and output. In social insect colonies, individual workers perform different tasks such as brood care, foraging, and others. Workers often differ in many traits, including body size. In bumble bees, worker body size variation is substantial (3-10fold within colonies). Overall, we show that smaller workers, while specializing on brood care over foraging, do not perform either task particularly well, and specifically are worse than larger workers. However, the optimal body size, taking into account production costs for workers, is different for brood care and foraging. Smaller workers perform less badly at brood care than they do at foraging, giving them a comparative advantage in this task, and generating a colony-level benefit of producing workers that differ in body size. We demonstrate theoretically that given a certain amount of resources to invest in producing workers, colonies do better by investing in a diversity of worker sizes, and that colony performance is driven more by the size of the largest workers than the average body size. We also show that how bumble bee colonies make these investment decisions under high or low food availability is consistent with this hypothesis. Our results indicate that benefits of worker diversity are varied and not restricted to producing highly efficient but narrow specialists.

108-4 DOWNS, AM*; KOLPAS, A; BLOCK, BA; FISH, FE; West Chester University, Stanford University; *ad846650@wcupa.edu*

Turning Performance by Bluefin Tuna: Novel Mechanism for Rapid Maneuvers with a Rigid Body

Scombrid fishes are known to attain exceptional swimming speeds due to their thunniform, lift-based propulsion, large muscle mass, and a rigid fusiform body shape. A rigid body should restrict maneuverability in regard to turn radius and turn rate for aquatic organisms. To test if turning maneuvers by the rigid-bodied Bluefin tuna (*Thunnus orientalis*) are constrained, captive animals were video recorded from above as the animals routinely swam around a large circular tank or during feeding bouts. The turning performance was observed and classified into three different types of turns: 1) Glide turn, where the tuna uses the caudal fin as a rudder to passively move through the turn, 2) Powered turn, where the animal uses continuous symmetrical strokes of the caudal fin to propel itself through the turn, and 3) Ratchet turn, where the overall global turn is completed by a series of small local turns by asymmetrical stokes of the caudal fin. Individual points of the rostrum, peduncle, and tip of the caudal fin were tracked and analyzed using Tracker software. Frame-by-frame analysis showed that the glide turn had the fastest turn rate at all three points tracked, with a maximum of 224.1 deg/sec. During the ratchet turn, the rostrum exhibited a minimum global turn radius of 0.43 m. However, the local turn radii were only 18.6% of the global ratchet turn. The minimum turn radii ranged from 0.38 m to 1.62 m as a proportion of body length. Compared to the performance of other swimmers, Bluefin tuna are not constrained in turning performance due to the rigid body because of flexibility of the tail and specialized turning behaviors.

41-5 DOWNS, CJ*; SCHOENLE, LA; MARTIN, LB; SUNY College of Environmental Science & Forestry and Hamilton College , Hamilton College and University of South Florida, University of South Florida; *cjdowns@esf.edu*

How Does Microbicidal Capacity of Serum Scale with Body Mass in Mammals?

Body mass is likely to affect the way organisms evolve, develop, and use immune defenses. We investigated how variation in microbicidal capacity of serum scales with body mass among >175 species of terrestrial mammals spanning 7-orders of magnitude in size. Specifically, we tested whether predictions derived from existing theories (e.g., Protecton Theory) best-predicted slope coefficient of the microbiocidal capacity of serum collected from healthy, zoo-housed adult animals against *Escherichia coli* (EC). We measured microbicidal capacity at 12 serum dilutions and fit a non-linear regression to the data to describe the full shape of the microbicidal capacity. We used the curve parameters as the response variables in our scaling models. A preliminary analysis showed that phylogeny explained less than 17% of the variation of each curve parameters for EC. We then used a mixed-effects, multivariable model to simultaneously estimate the interspecific scaling exponents (b) for the curve parameters. Our response variables had repeatabilities of 1-80%. Low repeatability for some parameters was a statistical artifact partially explained by species that switched from 100% killing to 0% at a dilution close to our least concentration samples. Large species needed less concentrated serum to kill 50% of EC (b = -0.22), had higher maximal killing capacities (b = 0.52), and had steeper killing slopes than small species (b = 8.0). These results indicate that the strength of constitutive microbicidal capacity increased disproportionately with body mass. They are consistent with the performance-safety hypothesis, but additional analyses of other forms of microbicidal activity are ongoing.

68-7 DREW, JA*; MCKEON, MG; State University of New York College of Environmental Science and Forestry, Columbia University; *jadrew@esf.edu*

Shark-based tourism presents opportunities for facultative dietary shift in coral reef fish

Tourism represents an important opportunity to provide sustainable funding for many ecosystems, including marine systems. Tourism that is reliant on aggregating predator species in a specific area using food provisioning raises questions about the long-term ecological impacts to the ecosystem at large? Here, using opportunistically collected video footage, we document that 61 different species of fish across 16 families are consuming tuna flesh at two separate shark dive tourist operations in the Republic of Fiji. Of these fish, we have resolved 55 to species level. Notably, 35 (63%) of the identified species we observed consuming tuna flesh were from ostensibly non-piscivorous fishes, including four Acanthuridae species, a group primarily recognized as browsers or grazers of algae and epibenthic detritus. Our results indicate that shark diving is having a direct impact on species other than sharks and that many species are facultatively expanding their trophic niches to accommodate the hyperabundance of resources provided by ecotourism.

11-7 DROWN, RM*; ANDERSON, CV; University of South Dakota; *rachel.drown@coyotes.usd.edu*

Does individual performance influence antipredator behavioral strategy choice in chameleons?

Animals are under a constant selective pressure to avoid predation. They are often equipped with several anti-predatory behavior strategies based on their morphology, physiology and behavior. Maintaining a suite of behaviors allows animals to choose strategies that may be better equipped for particular environments and types of predators. Chameleons are a particularly interesting model to study the relationship between these adaptations because of how they have specialized to their environment. These animals have adapted traits that are well-suited for a largely arboreal lifestyle, but as a consequence, produce relatively slow locomotion. As a result, they may need to rely on alternative strategies that do not hinge on speed. Chameleons may still choose to flee to avoid predation, but they may also undergo cryptic color changes or behave aggressively. Previous work also suggests that their antipredator strategies vary significantly with body size and habitat type. We examined the functional basis for variation in antipredator behavioral decisions in veiled chameleons (*Chamaeleo calyptratus*) of small, medium, and large size classes. Individuals underwent a series of mock predation trials and their behaviors were classified into "fleeing," "crypsis", "aggression", or "other." We then quantified the performance capacities underlying each strategy by measuring sprint speed and acceleration for fleeing, degree of color change for crypsis, and bite force for aggression. Our results indicate that certain performance capacities across size classes influence which strategy is chosen during mock predation trials. The importance of the functional capacity to perform each behavior in antipredator behavior decision making provides considerable insight into the relationship between behavior, environment, and physiology.

3-2 DUMAN, A*; AZIZI, E; University of California, Irvine; *aduman@uci.edu*

Olympians of Controlled Deceleration: Cane Toads Stick the Landing Across Surface Stiffness

Moving in the real world requires that animals – including humans – effectively maneuver obstacles and navigate terrain with complex properties. Variation in the mechanical properties of the environment, like surface compliance, can alter impact forces and energies that an animal must absorb and dissipate. *Rhinella marina*, the cane toad, is already a model species for understanding controlled decelerations which makes it an ideal organism for exploring the effects of surface compliance and damping on its locomotion. Using inverse dynamics during landing in toads (n = 8) we generated joint-level work across four compliance treatments (0, 2.5, 5 and 10 mm BW^{-1}) and two platform masses (123 and 725 g). We furthered our initial analyses by collecting muscle activity of the *palmaris longus, anconeus, pectoralis,* and *deltoideus* throughout 186 jumps from five toads landing on 0, 2.5 and 5 mm BW^{-1} compliance treatments. Our results suggest muscles at the shoulder are more involved as compliance increases and as surface damping increases while the elbow exhibits the inverse trend. We also found preparatory activation of forelimb muscles in a proximal-to-distal pattern which corresponds to observed shoulder protraction followed by elbow and wrist extension. Additionally, all four muscles investigated exhibit activity after impact providing support for our inverse dynamics findings across each joint. This work can help us understand how animals coordinate robust behaviors in the face of environmental variation.

39-2 DUNCAN, CM*; CHRISTIAN, H; CHMURA, H; BUCK, CL; BARNES, BM; LOUDON, A; WILLIAMS, C; Univ. of Alaska Fairbanks, Fairbanks, AK, Univ. of Oxford, Oxford, UK, Northern Arizona Univ., Flagstaff, AZ, Univ. of Manchester, Manchester, UK; *cmduncan3@alaska.edu*

Ultrastructural Changes of Reproductive Neuroendocrine and Endocrine Responding Cells Associated with Circannual Timing in a Hibernating Mammal

Reproductive timing strongly influences the fitness of individuals. While most vertebrates rely on changes in daylength to induce seasonal reproduction, the arctic ground squirrel (AGS) naturally undergoes reproductive maturity in a photoperiod-independent manner. In addition, male AGS spontaneously activate their reproductive axis during hibernation, but the timing of hibernation and reproduction are sensitive to external cues. We hypothesize that changes in pars tuberalis (PT) thyrotroph morphology underlie hibernation and reproductive phenology in a photoperiod-independent manner. We used electron microscopy to examine, define, and measure ultrastructural remodeling in PT thyrotroph cells, hypothalamic tanycytes, and pars distalis (PD) gonadotroph cells, as the AGS transitioned from hibernating to reproductively active. We also quantified how cell morphology corresponds with measures of reproductive axis outputs, including changes in sex steroid gene expression and development in the gonads, and plasma steroid concentrations. Finally, we examined mechanisms that underlie plasticity in hibernation and reproduction phenology, and whether hypothalamic and PD activity can become dissociated from the PT signaling pathway by assessing cellular remodeling in males placed in a 30&degC room during mid-winter, which induces early reproductive onset. This basic system-level investigation of reproductive control mechanisms may inform researchers on how cell ultrastructure influences connections between neuroendocrine circuits and the role these play in triggering puberty onset.

138-8 DUQUE, FG*; MONTEROS, M; NASIR, I; UMA, S; RODRIGUEZ-SALTOS, CA; CARRUTH, L; BONACCORSO, E; WILCZYNSKI, W; Georgia State U, Atlanta, GA, Inst Nacional de Biodiversidad, Quito, EC, Emory U, Atlanta, GA, U San Francisco de Quito, Quito, EC; *fduque1@student.gsu.edu*

Dialects in the high-frequency song of a hummingbird

Vocal signals convey information about affiliation, aggression, sexual state, and the identity of an individual. Variations in song structure across populations of the same species, known as dialects, have been described in frogs, birds, and mammals. The Ecuadorian Hillstar (*Oreotrochilus chimborazo*) is a hummingbird species in which males produce a high-frequency (HF) song (7-16 kHz) which consists of frequency-modulated introductory motifs followed by a series of trills. We investigated the variation in song structure of the HF song in this species to determine whether *O. chimborazo* exhibits dialects. We examined 8 populations along the Ecuadorian Andes, covering both subspecies, *O. c. jamesonii* and *O. c. chimborazo*. We found four dialects characterized by differences in the introductory motifs. The dialect found in the northern populations of *O. c. jamesonii* consists of an introductory whistle at 10 kHz, followed by a frequency-modulated introductory motif and trills at higher frequencies. The second dialect belongs to the subspecies *O. c. chimborazo*. Unlike the former, this HF song lacks the introductory whistle but instead, it exhibits two introductory motifs at 14.6 kHz. The third and fourth dialect songs are found in the two southern populations of *O. c. jamesonii*. These dialects differ from the others in the structure and number of introductory motifs. Although our findings map onto the microsatellite variation of the species, we found greater variability in the HF song than that present in the microsatellite analyses. These findings suggest that dialects may be the result of genetic variation and cultural evolution in the Ecuadorian Hillstar.

126-5 EARL, A.D*; KIMMITT, A.A; SIMPSON, R.K; YORZINSKI, J.L; Columbia University, Indiana University, University of Windsor, Texas A&M University; *ade2102@columbia.edu*

Female Ornamentation in a Lekking Bird: Bright Females Dominate

The study of male ornamentation has been fundamental to advancing our understanding of sexual selection, yet we are only now beginning to examine elaborate ornamentation of females. Although female ornamentation was once thought to be non-adaptive, recent studies have demonstrated that female ornamentation functions in both intrasexual competition and male mate choice; however, few studies have examined the role of female ornamentation in lekking species. We investigated the function and mechanisms of female ornamentation in Indian peafowl (Pavo cristatus), a lekking species in which females exhibit an elaborate ornament (iridescent green neck plumage). We tested whether female ornamentation predicts dominance status and whether female dominance affects courtship behavior. Finally, we examined whether steroid hormones (estradiol and corticosterone) are related to female ornamentation and dominance. We found that dominant females have brighter ornaments than subordinate females. Additionally, dominant females copulated more than subordinate females and prevented subordinate females from interacting with displaying males. Our data did not find a relationship between steroid hormones and ornamentation or dominance status. This study provides insight into the evolution of conspicuous female traits by suggesting a role for female ornamentation in intrasexual competition in a lekking species.

100-6 EBERTS, E.R*; GUGLIELMO, C.G; WELCH, K.C; University of Toronto Scarborough, University of Western Ontario; *ebertser@gmail.com*

Seasonal Changes in Body Composition and Torpor Use of Ruby-throated Hummingbirds (Archilochus colubris)

Hummingbirds can use torpor to reduce metabolic rate overnight as part of a strategy to manage daily energy balance or to maximize energy storage during certain life stages. However, the rules that govern torpor use are unclear. While torpor may be used only during times when energy stores fall below a critical level, an ‘emergency only' strategy may be abandoned to facilitate fat conservation prior to and 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 that entered torpor did so 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 (>20%). Overall, our preliminary results suggest that in the breeding season, hummingbirds use torpor only when their energy reserves are especially low. However, torpor use with high fat stores in the migratory season suggests that some individuals are able to use torpor to facilitate storage of fat needed to fuel their migratory journey. Ongoing analyses aim to explore individual variation and to elucidate the mechanistic link between torpor use, and seasonal changes in body condition.

138-2 ECHEVERRI, SA*; ZUREK, DB; MOREHOUSE, NI; University of Pittsburgh, Pittsburgh, University of Cincinnati, Cincinnati; *echeverri.sa@gmail.com*

Male Habronattus pyrrithrix Jumping Spiders Adjust Their Attention-Grabbing Courtship Display Based on Spatial and Environmental Context

To communicate effectively, signalers must capture the attention of potential receivers, and may do so with conspicuous "alerting" displays. Although many different animals use alerting displays, we know relatively little about how display variation and the sensory environment affect attention capture, especially in arthropods. In the jumping spider *Habronattus pyrrithrix*, males perform a complex courtship dance that includes elaborate movements and colorful ornaments. However, females can only see a male's colors when facing him. While females often turn away from courting males, males perform a waving display that may function to capture and/or redirect her attention. However, males show intraspecific display variation, which may be linked to spatial and/or temporal variation in the visual environments they display in. Using video playback, we asked how signal variation and visual environment affected how effectively a display attracted female attention. We then asked whether and how males respond to variation in their signaling environment. We found that increasing background complexity decreased female responsiveness in general, but male waving displays continued to effectively attract female attention even under increasingly complex signaling conditions. Males adjusted their displays in different signaling conditions by 1) performing larger waving displays when farther from the female, and 2) courting at a closer distance in more complex environments.These behaviors should improve signal effectiveness by increasing the size of the male display in the female's field of view. How well signalers manage receiver attention may be an axis for mate choice in this and other species.

65-1 ECHEVERRI, SA*; WETZEL, DP; BROUWER, NL; University of Pittsburgh, Pittsburgh; *echeverri.sa@gmail.com*

De-Jargonizing SciComm: Does having to use simple words make students better at writing for most people?

Scientists often have to share their work with people who are not experts in the same field, including students, the media, and politicians. However, the communication training offered at many undergraduate and graduate programs tends to focus only on how to talk to and write for other scientists. As a result, many scientists over-use complicated words with field-specific meanings ("jargon"), making understanding difficult. This bad habit can begin early in scientists' careers and become set over time.To improve how undergraduate students communicate their research, we asked how being required to write without jargon improved students' writing for non-experts. We asked students in a scientific communication course (n=16) to write a 250-500 word popular science article on a topic they were already researching for a semester-long project. We then challenged them to rewrite their first draft using only the 1000 most common English words, as inspired by the webcomic XKCD. Then, they wrote a final version with no restrictions. We used a rubric and the "DeJargonizer" online tool to ask how this improved the amount of jargon used, and the content and quality of the final article. Even with limited in-class practice, most students wrote competent articles for non-experts and successfully explained their topic without jargon when required. However, most students did not incorporate the phrasing and explanations from their jargon-free assignment into the final article, choosing instead to only edit their original draft. Despite this, several students said that they enjoyed the activity and felt that it helped them talk about their research in presentations. With modifications such as peer-feedback, this activity could be a fun way to improve science communications.

35-4 EDDINS, HMS*; KLIGMAN, BT; NESBITT, SJ; MARSH, A; PARKER, W; STOCKER, MR; Virginia Tech, Blacksburg, VA , Virginia Tech, Blacksburg, VA, Petrified Forest National Park, Petrified Forest, AZ, Petrified Forest National Park, Petrified Forest, AZ; *ehanna7@vt.edu*

New Triassic Reptile Reveals Oldest Record of a Complete Envenomation Apparatus

Little is known about the evolutionary history of vertebrate venom delivery systems owing to a sparse record of fossils preserving aspects of this morphology. Previously, only four Mesozoic reptile records existed: *Sinornithosaurus millenii* (Early Cretaceous: China), *Sphenovipera jimmysjoyi* (Early Jurassic: Mexico), *Uatchitidon kroehleri* (Late Triassic: Virginia, USA), and *Uatchitidon schneideri* (Late Triassic: North Carolina and Arizona, USA). Here we present a new, likely venomous, reptile collected from a microvertebrate-bearing horizon (~214 Ma; Norian age) in the Upper Triassic Chinle Formation of Arizona. This new taxon is represented by a fragmentary dentary bearing three conical, labiolingually-compressed teeth with mesially curved tips and ankylothecodont attachment. Each tooth bears a lingual and labial groove that extends from the base of the tooth to the apex. Computed tomographic data reveal foramina in the bone tissue at the base of each groove on either side that connect to internal cavities within the dentary. We interpret this morphology as an envenomation apparatus of venom glands within the dentary connected to venom-conducting grooves on the teeth, strongly convergent on the morphology of the extant squamate *Heloderma*. This new taxon is one of the oldest venomous reptiles and one of the only examples of a complete envenomation apparatus in the fossil record. The occurrence of the new taxon and records of *U. schneideri* in microvertebrate assemblages in the Upper Triassic of North America show that venomous reptiles were a common component of the vertebrate ecosystem in equatorial Pangaea.

109-6 EDMONDS, KE*; GIBSON, L; ROEDERER, L; Indiana University Southeast; *kedmonds@ius.edu*

Corticosterone and Estradiol Regulation of Gastrointestinal (GI) Development and Reproduction in the Marsh Rice Rat (Oryzomys palustris)

Environmental factors and subsequent hormonal changes can regulate the development of various physiological systems. Steroid hormones are known to affect significantly the reproductive system in seasonal breeders, but effects on the GI tract have not been as extensively studied. The present studies examined whether corticosterone or estradiol affect GI development and reproduction in juvenile male and female rice rats. Rice rats were subjected to subcutaneous Silastic implants of corticosterone or estradiol from 21-56 days of age. The following masses were examined: body, testes, seminal vesicles, Harderian glands (males only), spleen (males only), female reproductive tract, and wet (W) and dry (D) masses of the stomach (St), small intestine (SI), cecum (Ce), and colon (Co). In addition, small intestine and colon lengths were measured. Corticosterone had no effect on body mass or any reproductive or GI variable examined in males or females. Estradiol, on the other hand, increased female reproductive tract mass, WSt, WSI, DSt, and DSI masses relative to animals with empty implants, but decreased SI and Co lengths. These data show that estradiol most dramatically affects reproduction and GI development in females, but that corticosterone was without effect on any reproductive or GI endpoints in either sex. It was hypothesized that changes in the GI tract may be a necessary mechanism for coping with likely seasonal changes in metabolic requirements brought about by changes in steroid hormone levels. We are currently examining the effects of reducing steroids via ovariectomy on these same variables in females.

121-6 ELLIS, LV*; BOLLINGER, RJ; WEBER, HM; MADSEN, SS; TIPSMARK, CK; University of Arkansas, University of Arkansas and University of Southern Denmark, University of Southern Denmark; *lvellis@uark.edu*

Aquaporin Expression in the Gill of Japanese Medaka

Aquaporins (Aqps) are theorized to regulate cell volume homeostasis through water and solute transport. This study examined Japanese medaka (*Oryzias latipes*) gill Aqp1 and Aqp3 expression and localization in response to salinity challenges and osmoregulatory hormones, cortisol, and prolactin (PRL). Expression of *aqp3* was elevated in ion-poor water (IPW) compared to normal freshwater (FW), and very low transcript levels were observed in seawater (SW). Aqp3 protein levels decreased with acclimation to SW. Aqp1 expression however, was unaffected by salinity. PRL stimulated *aqp3* mRNA in *ex vivo* gill incubation experiments in both a dose and time-dependent manor, but was unaffected by cortisol. In contrast, *aqp1* was unaffected by both PRL and cortisol. The combination of cortisol and PRL had an additive stimulatory effect on *aqp3* , while *aqp1* remained unchanged. Confocal microscopy showed Aqp3 in the periphery of epithelial cells in gill filaments and co-localized at low intensity with Na^+,K^+-ATPase in ionocytes. While Aqp1 was found in most filament epithelial cells at low intensity and red blood cells, no immunoreactivity to Aqp3 or Aqp1 were found in the epithelial cells of the gill lamellae. We suggest that both Aqps contribute to cellular volume regulation in the gill epithelium and that Aqp3 is essential under hypo-osmotic conditions, while expression of Aqp1 is constitutive.

32-6 ELLIS, HI*; SAN FRANCISCO, S; University of San Diego, Texas Tech University; *ellis@sandiego.edu*

Sustained Metabolic Scope: Verification from Eared Grebe Time and Energy Budgets

Time-activity budgets of Eared Grebes (*Podiceps nigricollis*) have been measured at least four times at fall staging areas on two continents. We created a time-activity budget based on focal animal sampling on a post-wintering lake, Salton Sea, California and converted it to an energy budget based on respirometry studies done earlier on captive grebes. Our study covered five periods from late February to late April, 2014. We found that the amount of time devoted to specific activities changed with observational period, but that the grebes' daily energy expenditure (DEE) varied very little from a mean of 542 kJ/d and even less from a mean 2.4 x BMR. When we compared our study with those of fall staging grebes from other studies, we again found large variations in how the birds used their day, but consistency in DEE and again a 2.4 multiple of BMR. We believe the BMR multiple we are seeing in our non-breeding sedentary grebes represents the sustained metabolic scope (SusMS) predicted by Peterson et al. (1990) but never reported before as a recurring value in different situations.

81-8 ELLISON, CI*; MASLAKOVA, SA; Oregon Institute of Marine Biology, University of Oregon; *cellison@uoregon.edu*

Diversity of Benthic Nemerteans of the Caribbean

Unbeknownst to most people, the majority of species on Earth, especially in the marine environment, remain undescribed. In the context of the current biodiversity crisis, it is clear that characterizing existing diversity should be a priority, in order to establish a baseline for monitoring change. Biodiversity researchers must deal with the challenge of cataloguing the vast number of undescribed species while operating under deficit of time, funding, and taxonomic expertise. Characterizing undescribed diversity is further complicated by cryptic speciation, outdated and inefficient standards of species descriptions, and the need for revisionary systematics. Understudied taxa, like ribbon worms (phylum Nemertea), are in particular need of attention. In the Caribbean Sea there are ~38 described species of nemerteans, but DNA-barcoding of specimens collected over the past 20 years suggests there are several times that number of operational taxonomic units (OTUs), i.e. putative species, most of which are undescribed, cryptic, and a large fraction only known in the larval form. Preliminary species accumulation curves based on 108 OTUs (361 adult individuals as of early 2018) suggested a further ~50 species would be discovered by barcoding an additional ~1000 individuals. We now sequenced a few hundred additional adult individuals, and already surpassed the predicted number of species. How can we describe all of this diversity in our lifetimes? How does one deal with describing cryptic species (morphologically indistinguishable, yet distinct) or those only known as larvae? And how many species of nemerteans are there in the Caribbean Sea? Here we offer an update on the diversity of Caribbean nemerteans, and discuss some of the challenges associated with identifying and describing this diversity.

124-3 ELLISON, A; PACE, DA*; California State University, Long Beach; *douglas.pace@csulb.edu*

Protein metabolism and food-induced developmental plasticity during echinoid larval development

Previous research from our lab modeling energetic growth efficiency in larvae of the sand dollar, *Dendraster excentricus*, has shown that large-scale physiological plasticity occurs in concert with morphological plasticity during larval development in response to different food rations (1,000 and 10,000 algal cells ml^{-1}). In particular, low-fed larvae had higher protein growth efficiency (PGE, protein grown standardized to protein ingested) than high fed larvae early in development, but this advantage diminished rapidly and in later development, fell below that of high fed larvae. Given the importance of protein growth in planktotrophic larval development, we sought to further understand these large differences in PGE by measuring rates, costs, and efficiencies of protein metabolism in low- and high-fed larvae. While low- and high-fed larvae had similar mass-specific rates of protein synthesis, amino acid transport rates were almost 2-times higher in low-fed larvae. No differences were observed in either the energetic cost of protein synthesis (~ 5 J $(mg\ protein)^{-1}$) or the proportion of aerobic energy that was used to drive protein synthesis (~40% of metabolism). Major differences, which mirrored changes in PGE with development, were observed in protein depositional efficiency (PDE, protein growth standardized to protein synthesized). Low-fed larvae exhibited a decrease in PDE from 85% to 40% from 4 to 28 days post-fertilization while high-fed larvae increased from 55% to 65%. These differences in PDE provide a physiological explanation for the large differences in PGE between low- and high-fed larvae. These results demonstrate that protein metabolism is a critical response element in the developmental plasticity pathway of larvae experiencing different food environments.

100-8 ELOWE, CR*; GERSON, AR; University of Massachusetts Amherst; *crelowe@umass.edu*

Flux Capacity: Seasonal Changes in Body Composition and Metabolism in Migratory White-Throated Sparrows (Zonotrichia albicollis)

Migratory birds seasonally increase fat stores and the enzymatic capacity for fatty acid transport and catabolism to fuel long-distance migratory flights. However, catabolism of lean mass is also well documented in migratory birds and, if adaptive for migratory flight, seasonal changes in the capacity for protein metabolism should occur. To investigate seasonal changes in fuel storage and metabolism in preparation for migration, I conducted a photoperiod manipulation using captive White-throated Sparrows (*Zonotrichia albicollis*). I measured body composition and water-restricted metabolic rate through a "winter" photoperiod, and after exposing half the birds to a "spring" photoperiod. Lean mass peaked for all birds during the winter, but after photostimulation spring birds rapidly increased fat mass and the activity of fat catabolism enzymes while displaying peak *Zugunruhe*. There was a 25-fold increase in muscle sarcolipin transcript levels in spring birds, which may stimulate mitochondrial biogenesis and fat catabolism through sarco/endoplasmic reticulum Ca^{2+} ATPase (SERCA) uncoupling. Body composition remained stable in winter birds and metabolic rates did not differ significantly between seasons. However, spring birds lost more water for a given metabolic rate, driving greater rates of lean mass loss alongside altered protein catabolism enzyme activities. This suggests that protein may be catabolized at a greater rate during migratory seasons, potentially to cope with higher rates of water loss.

86-6 ELSHAFIE, SJ; University of California, Berkeley; *selshafie@berkeley.edu*

Body Size Changes Across Lizards and Crocodylians Correspond to Climatic Changes Through Deep Time

Climate is known to influence body size in living reptiles. However, this relationship has not been investigated over geologic time intervals, nor compared among higher-order groups of extinct reptiles. Here I test the hypothesis that body size range undergoes holistic, synchronized change in lizards and crocodylians in response to climatic transitions over geologic time scales. I estimate snout-vent length (SVL) in lizards and crocodylians from intermontane basins in the Western Interior of North America through the Paleogene (66-23 million years ago), spanning several warming and cooling periods. The range of SVL increases in both lizards and crocodylians in the early Eocene. Maximum SVL increases 4X in lizards relative to the middle Paleocene (150 mm vs. 600 mm) and doubles in crocodylians (1 meter vs. 2 meters) and remains elevated through the Eocene. Meanwhile, minimum SVL remains consistent through the Paleogene in both groups (approximately 100 mm in lizards, 200 mm in crocodylians). This pattern is observed with no consistent latitudinal gradient across intermontane basin communities through the Paleogene. The observed changes in maximum SVL correspond to changes in mean annual paleotemperature in the Western Interior through the Paleogene. These results suggest that climatic changes may drive overall body size changes in lizards and crocodylians over deep time scales.

63-5 EMBERTS, Z*; ST. MARY, CM; FORTHMAN, M; MILLER, CW; University of Florida; *emberts@ufl.edu*

The evolution of autotomy in leaf-footed bugs

Sacrificing body parts is one of many behaviors that animals use to escape predation. This trait, termed autotomy, is classically associated with lizards. However, several other taxa also autotomize, and this trait has independently evolved multiple times throughout Animalia. Despite having multiple origins and being an iconic anti-predatory trait, much remains unknown about the evolution of autotomy. Here, we combine morphological, behavioral, and genomic data to investigate the evolution of autotomy within leaf-footed bugs and allies (Insecta: Hemiptera: Coreidae + Alydidae). We found that the ancestor of leaf-footed bugs autotomized, and did so slowly (> 15 min). Rapid autotomy (< 2 min) then arose multiple times. The ancestor likely used slow autotomy to reduce the cost of injury or to escape non-predatory entrapment, but it is unlikely that autotomizing this slowly would be advantageous during a predation event. This suggests that autotomy to escape predation is a co-opted benefit (i.e., exaptation), revealing one way that sacrificing a limb to escape predation may arise. We also found that across species variation in the rates of autotomy can be explained by body size, distance from the equator, and enlargement of the autotomizable appendage.

16-1 ENGLISH, P; SILVERTHORN, DU*; University of Texas at Austin; *silverthorn@utexas.edu*

The Minimal Marking Technique: Grading Writing Assignments while Promoting Active Learning

Requiring students to write can enhance their analytical, elaboration, and critical thinking skills while giving them an opportunity to explore the scientific literature. Writing out ideas is a very different process than correctly answering content-laden multiple choice questions, and many students do not get enough writing experience in their science classes. One reason may be that for the instructor, grading and commenting on a large number of student writing assignments is time consuming. It is also frustrating, since simply copy-editing student work often has no impact on the student's writing, with the same errors showing up repeatedly. Minimal marking is a grading technique in which minimal feedback based on structured error codes requires students to actively engage in the editing process. It is faster and simpler for the grader, and it improves awareness of writing skills for the student. In this presentation we will demonstrate how to use the minimal marking technique, with examples from a writing-intensive inquiry lab course.

18-5 ENNS, JL*; PURDEY, L; STOJKOVIC, L; WILLIAMS , TD; Simon Fraser University; *joannae@sfu.ca*
Is Coordination Key? Investigating the Timing of Provisioning Visits in a Biparental Songbird Species
Parental care increases the inclusive fitness of parents by increasing offspring survival. However, in species that take part in biparental care, there is sexual conflict due to differential costs of investment, where each parent benefits from their partner putting in more effort. Turn-taking (or coordination) of nest visits during chick provisioning has been suggested as a strategy to mitigate this conflict. In order for coordination to work, each bird must have access to information about its partner's behaviour, allowing pairs to respond to each other "in real time". To date, evidence in support of this type of cooperation has come from species that forage close to the nest (within 45 m) and/or synchronize feeding visits, which likely provides direct information for each partner. We aim to fill this literature gap by investigating variation in feeding-visit intervals in the European starling, *Sturnus vulgaris*, where foraging distance is greater (~800 m) and therefore direct information on the partner's behaviour is likely less available. Considering feeding-visit interval as a behavioural phenotype, we tested the hypothesis that parents adjust their interval length based on knowledge of their partner's feeding behaviour (or indirect cues via chicks). Preliminary analysis suggests feeding-visit interval is a plastic trait, and may vary among years, 1st and 2nd broods, and with brood size. Finally we describe an experiment to directly test the coordination hypothesis, removing one bird during chick-rearing and then measuring their partner's ability to respond to manipulation of this putative 'information cue'.

92-1 ENSMINGER, DC*; PRITCHARD, C; GINGERY, T; LANGKILDE, T; University of California, Berkeley and The Pennsylvania State University, The Pennsylvania State University; *dls_david@yahoo.com*
The influence of hunting pressure and ecological factors on fecal glucocorticoid metabolites in wild elk
Climate change and a growing human population have increased anthropogenic threats to biodiversity and habitat fragmentation. Ecologists and conservationists have focused on how to assess the effect of these ecological and environmental perturbations on organismal fitness. Glucocorticoids (e.g. cortisol and corticosterone, CORT) are commonly used to assess animal welfare as they integrate various factors such as anthropogenic disturbances, predation, food, or environmental stressors. Here we tested the hypothesis that anthropogenic hunting pressure increases fecal CORT metabolites (fecal GCM) in wild female elk (*Cervus elaphus*) and examined the influence of herd size, year, and food availability on fecal GCM. We found a trend for decreased fecal GCM with as the hunting season progressed. We also found a negative relationship between fecal GCM and number of cows in the herd, and a strong effect of year on fecal GCM, with samples collected in 2016 having lower CORT than those collected in 2015, 2017, and 2018. However, yearly variation was not driven by availability of hard mast forage. The potential negative association between hunting pressure and CORT and identifying what is driving yearly variation in CORT warrants further study. We highlight the influence of herd size, possibly due to vigilance, on fecal GCM and the importance of examining ecologically relevant covariates to accurately identify main treatment effects, such as hunting pressure.

131-7 ERDMANN, JA; Oklahoma State University; *james.erdmann@okstate.edu*
Aggressive anglers, seductive serpents, and titillating toads: a discussion of luring and prey manipulation strategies
When a predator hunts a cryptic or mobile prey item, it has two general options: actively seek out the prey or remain stationary and wait for prey to approach. In the latter case, predators employ an assortment of strategies to increase the encounter rate of their prey-to-be. Perhaps the most recognizable of these strategies is the lure, wherein the predator creates some attractive stimulus to their potential prey, causing the prey to unwittingly approach the predator. However, the literature is equivocal on what constitutes a lure, as well as how to go about testing it. I critique the conditions when the term 'lure' is applied and suggest ways of quantitatively measuring it against behavioral alternatives to create a more robust foraging theory.

33-6 ESBAUGH, A.J*; LONTHAIR, J; University of Texas at Austin , University of Texas at Austin; *a.esbaugh@austin.utexas.edu*
The Development of Acid-base Pathways in Marine Fish: Implications for Ocean Acidification
Ocean acidification (OA) caused by elevated carbon dioxide is an imminent environmental stress to marine organisms, and is hypothesized to have a suite a detrimental effects. In fish, elevated carbon dioxide causes a respiratory acidosis that is compensated through ion transport pathways at the gills. This disturbance is thought to be the underlying cause of many of the effects of OA, including reduced survival in many marine fish larvae. Importantly, little is known about the development and function of acid-base pathways in marine fish larvae. We therefore sought to explore the development of acid-base pathways in a model marine fish, the red drum (*Sciaenops ocellatus*), and assess the role of phenotypic plasticity in early life resilience to carbon dioxide stress. We first explored the dose response effects of carbon dioxide, which resulted in significant reductions in larval survival at OA relevant partial pressures. However, a significant proportion of tested individuals also exhibited surprising resilience to carbon dioxide with approximately 50% survival when exposed to partial pressures over 10x those relevant to OA. Gene expression and confocal microscopy were used to assess acid-base pathways, which provided evidence for functional pathways and CO2-induced plasticity as early as 36 hours post-fertilization. A scanning ion electrode technique was used to verify the function of these pathways, which was evident from a dose-dependent increase of proton flux across the larval epithelium. Interestingly, proton flux was both bafilomycin-sensitive and EIPA-sensitive suggesting the presence of multiple acid excretion mechanisms, which likely contributes to the observed resilience of red drum to carbon dioxide stress.

60-4 EVANS, KM*; SPERSTAD, ZE; WESTNEAT, MW; Brown University, University of Minnesota, University of Chicago; *kory_evans@brown.edu*

Evolutionary Convergence and Constraints on the Skull Shape of Burrowing Wrasses

The evolution of behavioral and ecological specialization can have marked effects of the tempo and mode of phenotypic evolution. Head first burrowing has been shown to exert powerful selective pressures on the head and body shapes of many vertebrate and invertebrate taxa. In wrasses (Labridae: Percomorpha), burrowing behaviors have evolved multiple times independently, and are commonly used in foraging and predator avoidance behaviors. While recent studies have examined the kinematics and body shape morphology associated with this behavior, no study to date has examined the macroevolutionary implications of burrowing on patterns of phenotypic diversification in this clade. Here, we use three dimensional geometric morphometrics and phylogenetic comparative methods to study the evolution of neurocranium shape in fossorial wrasses and their relatives. We test for skull shape differences between burrowing and non burrowing wrasses and evaluate hypotheses of shape convergence among the burrowing wrasses. We also quantify rates of skull shape evolution between burrowing and non burrowing wrasses to test for whether burrowing constrains or accelerates rates of skull shape evolution in this clade. We find that burrowing wrasses and non burrowing wrasses exhibit similar degrees of morphological disparity and exhibit indistinguishable rates of skull shape evolution. These results suggest that patterns of skull shape diversification in wrasses are not constrained by head-first burrowing and that several phenotypes are capable of this behavior.

S2-4 EYCK, HJF; SARMA, RR; CRINO, OL; WATERS, PD; CROSSLAND, M; SHINE, R; ROLLINS, LA*; UNSW, Sydney, NSW, Deakin University, Geelong, VIC, Macquarie University, Sydney, NSW; *l.rollins@unsw.edu.au*

Corticosterone response to experimental manipulation of methylation in invasive amphibian larvae

The role of epigenetic variation as a powerful driver of evolution has received increased attention in recent years. In endocrine systems, it is well-established that the methylation status of certain genes can affect the expression of hormone receptors and patterns of hormone release. For example, across taxonomic groups, epigenetic alterations have been linked to changes in glucocorticoid (GC) physiology. GCs are important metabolic hormones that influence growth/development, transition between life-history stages, and fitness. Few studies to date have examined the role of epigenetic modifications in altering phenotypic traits and fitness in wild animals. Here, we examined the effects of experimentally manipulated epigenetic status on genome-wide methylation and CORT patterns in cane toad (*Rhinella marina*) tadpoles. Cane toads are non-native to Australia and have rapidly expanded their range across the continent, displaying considerable variation with respect to morphology, behavior and epigenetic status. Here, we manipulated methylation via exposure to zebularine and/or predator alarm cues and examined genome-wide methylation patterns and whole animal CORT metabolites at late stages of tadpole development to determine the impacts of these treatments. In full siblings of these individuals, we examined the effects of methylation treatments on time to metamorphosis, adult morphology, and survival. We found that both treatments result in altered methylation, faster time to metamorphosis, and changes in adult morphology and survival. We discuss these results in relation to treatment-induced changes in CORT physiology and the role that epigenetics plays in rapid evolution during invasions.

118-2 FABRE, A-C*; BARDUA, C; CLAVEL, J; FELICE, RN; BONNEL, J; BLACKBURN, D; STANLEY, E; STREICHER, J; GOSWAMI, A; The NHM, UK, UCL, UK, University of Florida, Florida, USA; *fabreac@gmail.com*

Morphological evolution of the head of Caudata is correlated to rapid diversification and dispersion during warming events

A positive correlation between diversification and rate of phenotypic evolution is predicted by several evolutionary theories, from the ecological theory of adaptive radiation to the hypothesis of punctuated equilibrium. However, most studies of this effect are limited in sampling or representation of morphology. Here, we investigate the relationship between rate of morphological evolution and diversification in the salamander skull using surface geometric morphometrics. These data were gathered for 148 species belonging to all extant families of salamanders. We conducted analyses of taxonomic diversification and rate of cranial evolution in this dataset. Our results demonstrate an increase of the rate of cranial evolution during the Late Cretaceous and the Paleocene-Eocene thermal maxima. These two warming events correspond to diversification and dispersal events in Caudata, as well as in several other clades, such as angiosperms, arthropods, and birds. The high diversification and rate of morphological evolution observed approximately 50 million years ago also correspond to the sole invasion of tropical regions by plethodontids, as well as to their transcontinental dispersion in the northern hemisphere. Our results demonstrate that rate of salamander cranial shape evolution increases during episodes of global warming, alongside increases in taxonomic diversification and geographic dispersal. Further analysis of fine-scale patterns of climate change, niche availability, and their interactions with life history and ecology will provide important new insights into the causes of these increased rates of evolution, diversification, and dispersal in Caudata during periods of global warming.

138-7 FALK, JJ*; RUBENSTEIN, D; WEBSTER, M; Cornell University, Ithaca, NY and Smithsonian Tropical Research Institute, Panama, Columbia University, New York City, NY, Cornell University, Ithaca, NY; *j.jinsing@gmail.com*

Female hummingbirds with male-like coloration may avoid aggressive interaction at food resources

A major source of variation in the animal kingdom stems from differences between the sexes. This concept, sexual dimorphism, is typically studied across species with a phylogenetic approach, but can also be studied within species if variation in dimorphism exists (i.e. when one sex varies in similarity to the other). Though frequently found in males, this type of variation is relatively rare in females. Female-limited polychromatism is an evolutionary conundrum because theories typically used to explain ornamentation (e.g. sexual selection) do not readily explain the observed variation in females. Many hummingbird species contain female-limited polymorphism. In one, Florisuga mellivora, ~30% of females captured had ornamented plumage nearly identical to that of the male, while the others had drab coloration. The contexts in which male-like coloration in females might have evolved have not been previously studied, but sexual or territorial harassment have been hypothesized. We observed interactions of wild hummingbirds with taxidermy mounts of male-like females, drab females, and true males at feeders. Male F. mellivora attempted copulations with drab females more often than with male-like females. However, territorial attacks were also more often directed toward drab females than both male-like females and true males. Territorial behavior toward drab female mounts was more frequent than sexual behavior, and sexual behavior in the wild was seen much less often than territorial behavior toward females. Therefore, both sexual and territorial contexts could be relevant, but territorial harassment may be a more important context for the evolution of male-like coloration in female hummingbirds.

136-4 FALTINE-GONZALEZ, DZ*; LAYDEN, MJ; Lehigh University; *dzf215@lehigh.edu*

Determining the role of oral-aboral patterning on neurogenesis in the sea anemone, Nematostella vectensis

Cnidarian nerve nets are believed to represent the ancestral nervous system that gave rise to centralized nervous systems (CNS), a trait of bilaterians. Determining how neural patterning occurs in the net-like ancestral nervous system will allow us to understand the origin and evolution of patterning mechanisms that gave rise to the CNS. Previous work identified neurogenic programs that act broadly to specify *N. vectensis* early neurogenesis, yet the mechanisms that specify neural subtypes are poorly understood. Our work aims to improve our understanding of the developmental mechanisms that control neuronal fate. Previous work suggests that the Wnt gradient established oral-aboral (OA) axis of *N. vectensis* is homologous to the AP axis of bilaterians, and that molecularly defined spatial domains along the OA axis are like those found to pattern the CNS along the AP axis. We hypothesized that spatial domains established by axial patterning cues contribute to neuronal patterning in *N. vectensis*. To test this, we disrupted the cnidarian aboral domain marker *Nvsix3/6*. Loss of *Nvsix3/6* resulted in loss of aboral neural genes while misexpression of *Nvsix3/6* expanded aboral neural gene expression orally. As *Nvsix3/6* is known to regulate known Wnt inhibitors we wanted to confirm that *Nvsix3/6* promotes aboral neuronal fates directly, independent of suppressing Wnt activity. To test this, we overexpressed *Nvsix3/6* in animals treated with the Wnt agonist azenkenpallone. In a high Wnt background, *Nvsix3/6* promoted aboral neural gene expression suggesting that the Wnt gradient patterns the OA axis and neural subtypes in parallel. Our data demonstrate a link between Wnt patterning and neuronal specification in cnidarians and bilaterians but suggest that in bilaterians Wnt signaling specifies axial domains, which in turn promote neuronal fate specification.

82-4 FARALLO, VR*; MUOZ, MM; Yale University; *vfarallo@gmail.com*

Out of time and out of room: Are montane salamanders vulnerable to extinction due to climate change?

In response to global climate change, many terrestrial species are shifting their ranges poleward or upwards in elevation. Montane species with restricted ranges, however, are limited in their ability to do so and are especially threatened by rising temperatures. Lungless salamanders (Family: Plethodontidae) are highly diverse in the Appalachian region of the United States. This group includes species with extremely wide ranges, like *Plethodon cinereus*, as well as several species restricted to small ranges at high elevations. Understanding, the specific mechanisms that dictate geographic range limits will be critical for mitigating negative impacts of climate change and preserving biodiversity. We will present data on the metabolic, thermal, and hydric physiology of three species of plethodontid salamanders: a widespread species, *Plethodon cinereus*, and two montane endemics, *P. hubrcihti* and *P. sherando*. We examine differences in their physiology including thermal tolerances, thermal preference, metabolic rate, and water loss rates. We integrate these data with field measures of habitat use in a mechanistic niche framework to assess shifts in conditions under future climate scenarios. We then use these data to discuss the best approaches to conserve geographically-restricted species under rapidly changing environments.

106-3 FARIA, S*; GOODBODY-GRINGLEY, G; MARANGONI, L; PEREIRA, C; BATEMAN, S; ZILBERBERG, C; MIES, M; KITAHARA, M; BIANCHINI, A; GARLAND, T; NAVAS, C; Bermuda Institute of Ocean Sciences, Monaco Scientific Center, Federal University of Rio de Janeiro, University of São Paulo, Federal University of São Paulo, Federal University of Rio Grande, University of California, Riverside; *scoelhofaria@gmail.com*

Brazilian Phenotypic Plasticity under Climate Changes: an Evolutionary History Scripted in the Coral-Dinoflagellate Symbiosis

A functional symbiotic association between cnidarians and photosynthetic dinoflagellates is widespread in shallow-water corals. Photosynthesis reaches up to 98% of energetic requirements in corals from oligotrophic environments; heterotrophy contributes up to 60% of the energy demand in eutrophic or turbid waters. Bermuda and Brazilian reefs illustrate such opposing water physicochemistry concerning nutrient status and light availability. We evaluated symbiont density and chlorophyll *a* content in 18 coral species from both sites under natural conditions and simulated climate changes (-0.3 pH/+2.5 ºC), followed by phylogenetic comparisons. We tested for higher symbiont density and chlorophyll *a* content in Bermuda corals; higher tolerance to bleaching in the Brazilian ones; and an environmentally driven evolution of coral-dinoflagellate symbiosis. Under natural conditions, symbiont density was greater in Bermuda; chlorophyll *a* content did not differ between sites. After treatment, mean symbiont density reduced 30% in corals from both sites. However, despite that mean chlorophyll *a* content reduced 10% in the northern corals, the Brazilian species increased it in 90%, meaning up to a 7-fold boost in the amount of chlorophyll *a* per symbiont. These results reveal strong plasticity in the Brazilian corals, a resilience without phylogenetic effect and potentially driven by the greater water nutrient status, suggesting higher energy budget to the holobiont during bleaching.

90-5 FARINA, SC*; AMACKER, K; CHENNAULT, M; GIBB, AC; Howard University, Northern Arizona University; *stacy.farina@howard.edu*

Kinematic integration of gill chamber pumping with body movements during burial in two morphologically disparate fish species

The ability to bury in sediment has evolved numerous times throughout the actinopterygian phylogeny. Each group that adopts this behavior must co-opt existing structures, leading to a variety of burial strategies. The majority of burying fishes fluidize sediment by injecting water into the substrate, but the structures involved and how they are used varies widely across groups. In this study, we used high speed video and intracranial pressure recordings to document the use of gill chamber pumping, in coordination with body and fin movements, in two highly disparate species: Isopsetta isolepis (a flatfish) and Leptocottus armatus (a sculpin). Like all flatfishes, I. isolepis has two eyes on one side of its head, and it lays on its lateral surface, with the blind-side gill chamber contacting the substrate and the eyed-side gill chamber pointing upward. In coordination lateral body undulations, I. isolepis passes water out of the blind-side gill opening to fluidize sand, which is facilitated by an anatomical shunt between the eyed and blind-side gill chambers. In contrast, L. armatus is a dorsoventrally compressed sculpin. In coordination with dorsoventral undulation and fin movements, L. armatus uses its left and right gill chambers simultaneously to fluidize sand. The flatfish approach is substantially faster than the sculpin approach, although both strategies are highly effective.

116-5 FARRAR, VS*; VIERNES, RC; FLORES, L; CALISI, RM; University of California, Davis; *vsfarrar@ucdavis.edu*

Prolactin maintains a parental phenotype in both sexes of the biparental rock dove

Parents of many species often experience reduced sexual behavior and fertility while caring for young to prioritize offspring survival. To test how such reproductive trade-offs are mediated, we investigated the role of prolactin in promoting parental behaviors over sexual ones. As in mammals, prolactin drives avian parental care, including ”lactation” in both sexes of the biparental rock dove (*Columba livia*). These traits make rock doves an ideal model for investigating the effects of prolactin on the maternal and paternal brain without the potential for sex-biased confounds of lactation. To test how prolactin alters behavioral priorities, we first removed the nests and eggs chicks of actively breeding pairs, forcing birds to experience a drop in circulating prolactin and revert back to a sexually active, non-parental state. Then, we experimentally manipulated their prolactin levels to reinstate circulating concentrations seen during the parental care period. When offered novel chicks, both sexes given prolactin retained their parental care behaviors, unlike controls, suggesting that elevated prolactin can maintain a parental phenotype, even after loss of a nest. Now, we are testing the effect of prolactin on gene activity of key reproductive neurohormones and their receptors to determine causal mechanisms behind this behavioral shift.

49-5 FASSBINDER-ORTH, CA; Creighton University, Omaha, NE; *carolfassbinder-orth@creighton.edu*

Effects of Arbovirus Infections on Digestive Physiology, Growth, and Survival in Young Animals

Arthropod-borne virus (arbovirus) infections are known to exhibit age-dependent patterns of virulence in their hosts, with the young and old often being the most susceptible to severe infection. In very young mammals and birds, infections with a specific class of arboviruses, called alphaviruses, often result in neuroinvasive disease, impaired growth, and digestive function disturbance. The mechanism by which these viruses impair growth and digestive function is likely complex and not fully understood. In birds, developmental and digestive impairment due to alphavirus infection is evident in both precocial and altricial nestlings, although more severe disease symptoms have been recorded in my laboratory in altricial nestlings compared to precocial nestlings. Alphavirus infection impairs bone growth, tissue maturation, digestive enzyme production, and digestive efficiency in altricial nestling birds in laboratory settings and growth impairment and poor survival have been recorded in nestling birds with alphavirus infections in the wild. This work highlights the high cost of viral infections in young animals and the potentially dire consequences on development and survival.

87-6 FATH, M*; NASIMI, F; TYTELL, E ; Tufts University; *michael.fath@tufts.edu*

Kinematic responses to rolling perturbations during swimming in the bluegill sunfish

Many fishes are unstable in roll. Staying upright thus requires constant coordinated input from multiple fins. To quantify how fish maintain roll stability, we developed a miniature device that produces a controlled jet of water. We sutured it on to bluegill sunfish (*Lepomis macrochirus*), so that they would receive a brief rolling perturbation during swimming at 3 speeds. We measured the kinematics associated with swimming before, during, and after the perturbation, and quantified the time it took the fish to recover. Before the perturbation, the pectoral fins we synchronized in phase or roughly 180 degrees out of phase, but did not coordinate with the caudal fin. The pectoral fin contralateral to the perturbing device was extended to dampen the roll and the fish was able to return to pre-perturbation swimming kinematics within 1.2 seconds at lower swimming speeds and within 0.9 seconds at higher swimming speeds.

81-5 FEILICH, KL*; NITTA, JH; FRIEDMAN, M; University of Michigan, Ann Arbor, Smithsonian Institution, Washington, DC; *kfeilich@umich.edu*

Distribution of morphological diversity, phylogenetic diversity, and speciation rate of freshwater fishes of the United States

The freshwater fauna and hydrography of the United States has been the subject of intense study for more than a century, resulting in an abundance of data concerning the environment and composition of these freshwater communities. We harnessed existing species distribution and phylogenetic resources and joined them with a novel body shape dataset for more than 900 species of freshwater fishes native to the contiguous United States to determine how the spatial distribution of species richness relates to morphological and phylogenetic diversity, and to speciation rate. Species richness of freshwater fishes in the United States follows the drainage patterns of major river basins, with the most diverse communities in the lower Mississippi River basin and southeastern Appalachia. Analysis of phylogenetic diversity revealed a similar pattern, with a small number of phylogenetically over-dispersed communities localized to the Mississippi delta and the southern Atlantic coast. Morphometric diversity was highly correlated with phylogenetic diversity. Although species richness is highest in the eastern half of the country, speciation rate was highest in the west. These distributions suggest exogenous geographic controls on the distribution of species richness and speciation rate.

37-6 FELICE, RN*; POL, D; O'CONNOR, PM; GOSWAMI, A; UCL, London, CONICET, Trelew, Ohio University, Athens, OH, NHM, London; *ryan.felice@ucl.ac.uk*

Crocodyliform Cranial Constraint and Convergence

Mesoeucrocodylia (alligators, crocodiles, gharial, and their extinct relatives) is a surprisingly diverse clade of archosaurs that includes carnivorous, omnivorous, herbivorous forms that once occupied a wide range of habitats. Whereas the crown group is comparatively uniform in their morphology, this apparent lack of variation may be a result of functional or developmental bias or homoplasy due to shared semi-aquatic ecology. Here, we investigate the dynamics of skull shape evolution to understand how rates of evolution and disparity have varied across mesoeucrocodylian lineages through time. Previous investigations of skull evolution in the group have focused on subgroups or on 2D geometric morphometric approaches that exclude key aspects of cranial variation (e.g., palate and pterygoid). We quantify whole-skull morphology across the diversity of Mesoeucrocodylia (n=45, including 19 fossils with 7 notosuchians, 2 thalattosuchians, and 10 crocodylians) using high-dimensional geometric morphometrics (1291 surface landmarks and semilandmarks). The most variable parts of the skull are the pterygoid and ectopteryoid, as well as the premaxilla, illustrating that other parts of skull shape beyond craniocaudal elongation are important parts of morpho-functional diversification in this clade. Modelling phenotypic evolution under a variable-rates Brownian motion model reveals high posterior probability of increased rates of evolution at the split between Crocodilia and Alligatoridae and on the terminal branches, suggesting rapid evolution in the crown group. Phenotypic integration is negatively correlated with disparity, supporting the hypothesis that intrinsic bias has constrained cranial evolution. Together, this whole-skull approach illustrates the importance of constraint and convergence in crocodyliform skull evolution.

51-3 FELLER, KD*; SUPPLE, J; GONZALEZ-BELLIDO, PT; Univ of Minnesota, Univ of Cambridge; *kfeller@umn.edu*

Multimodal sensory responses from descending neurons in Squilla stomatopod crustaceans

Though stomatopods (commonly known as mantis shrimp) possess one of the world's most complex visual sensors, we know very little about how this information is used to modulate the animal's motor outputs. Behavioural experiments demonstrate that mantis shrimp modulate their strike speed relative to incoming sensory information, which led us to hypothesize that interneurons in the descending nerve cord encode this information. To test this, two electrophysiological preparations were developed to record from descending neurons in the circumesophogeal connectives (CECs) in t*Squilla mantis* and *Squilla empusa*. During recordings, animals were presented with a variety of visual stimuli as well as tactile stimulation to the anterior antennae. Robust responses were observed in response to looming and moving target visual stimuli, and light touches to the primary antennules. Both looms and mechanical stimulation of the antennules were associated with recruitment of the strike muscles. Light microscopy revealed a population of 7-8 extremely large (50-100 µm) diameter axons that are hypothesized to be the source of these large extracellular responses. These interneurons are good candidates for targeting future intracellular recording experiments in stomatopods and are hypothesized to relay multimodal information from the cerebral ganglion to the inferior motor centers, including the strike motor centers in the subesophogeal ganglion. This study is the first to present stomatopods as a tractable system for investigating the neuroscience principles that govern predictive movement.

105-7 FELTMANN, A*; GIFFORD, M; FIELD, E; University of Central Arkansas; *afeltmann1@cub.uca.edu*

Effect of Selection and Genetic Drift on Phenotypic Diversification in the Eastern Collared Lizard

Organisms display a wide diversity of traits that selection acts upon causing phenotypic change over time. When organisms disperse, however, the resulting small population can experience genetic drift due to decreased genetic diversity within the population. Reintroduction is a common form of population restoration in conservation management plans. The reintroduced populations face challenges that colonizing populations face (i.e. a reduced population number and possible inbreeding). These issues may lead to genetic drift which can majorly impact fitness in the population, potentially leading to population crash. We examined the effects of selection and drift on a metapopulation of the Eastern Collared Lizard (*Crotaphytus collaris*) on Stegall and Thorny mountains in southern Missouri. We measured a suite of morphology and performance traits to assess levels of differentiation between mountains and developed a phenotypic variance-covariance matrix (***P***). Multiple matrix analyses suggest that ***P*** and the levels of covariation between traits differ between populations. Additionally, univariate analyses suggest some traits have diverged between mountains.

112-5 FETKE, JK*; FLICK, RW; MARTINSON, JW; SEE, MJ; PILGRIM, EM; BIALES, AD; University of Cincinnati, US EPA, Cincinnati, OH, US EPA; *fetkeje@mail.uc.edu*

Investigating the effects of DNA methylation on EE2 induction of Estrogen Receptor alpha gene expression in fathead minnows (Pimephales promelas)

Estrogens present in the environment interfere with endocrine function and cause decreased fecundity, fitness, and sperm production in fish, as well as feminization of male fish. Physiological effects and alterations of gene expression resulting from estrogen exposure have been thoroughly described in fish. Despite this, little is known about epigenetic alterations, although these changes are believed to provide the critical linkage of gene expression with the development of adverse effects at higher biological levels. This study investigates alterations of DNA methylation of *estrogen receptor alpha (ER& lpha;)* in brain and liver tissue in fathead minnows *(Pimephales promelas)* exposed to either 2.5 ng/L or 10 ng/L of the synthetic exogenous estrogen, 17 -ethynylestradiol (EE2). Methylation differences were assessed across all CpG sites in a 2.5KB region encompassing exon 2 and 1.5KB upstream of the start site of the *ER& lpha;* gene by targeted deep sequencing of bisulfite treated DNA isolated from liver and brain tissue. Additionally, DNA methylation was assessed from fish depurated for 7 and 14 days to determine the kinetics of methylation. Finally, relationships between *ER& lpha;* methylation status and gene expression for individual fish were evaluated. Results from this work will provide information regarding the drivers of response to estrogens and the linkage between alterations in methylation status and gene expression.

71-6 FIALKO, KY*; PRICE, TP; University of Chicago; *fialko@uchicago.edu*

Comparative kinematics of Phylloscopus warbler territorial display behaviors

The relationship between animal signals and signaling environment is an active area of research, especially with regard to the adaptation of animal color with respect to visual environment. Recent studies in visual communication have integrated behavior, exploring the interaction between static color signals and dynamic visual displays. However, only recently have all three components – color, display and environment – began to be analyzed together. Old World leaf warblers in the genus *Phylloscopus* are a classic example of the Sensory Drive Hypothesis. In the Western Himalaya, previous research has shown a correlation between habitat darkness and degree of ornamentation, such that species occupying darker habitats have a greater quantity of plumage patches (Marchetti 1993). However, motion in the form of display behaviors also plays a key role in how a visual signal is presented and perceived. With the accessibility of affordable high-speed video cameras, these rapid behaviors can now be quantified and analyzed. We filmed territorial display behaviors of 7 species of *Phylloscopus* warbler and one *Horonis* warbler in the Western Himalaya. We then analyzed the display behaviors by tracking trajectories of wing motion and quantifying shape changes and wing flick rate. Significant variation was found in both the trajectory of wing display behaviors as well as wing flick rate. This work broadly confirms that species with signaling patches tend to display their wings, and this behavior varies interspecifically. A notable exception is in one species that has no patches but lives in exceptionally dark habitats. We discovered this species has a hidden, achromatic patch that is only visible during display, likely functioning in short-range communication.

31-2 FIFER, JE*; BUI, V; BERG, J; GABRIEL, M; BENTLAGE, B; DAVIES, S; Biology Department, Boston University , Marine Laboratory, University of Guam, Marine Laboratory, University of Guam; *jfifer@bu.edu*

Coral Microbial Community Shifts Along a Steep Environmental Gradient

Reef-building corals form complex relationships with a wide range of microbial partners, including symbiotic algae in the family Symbiodiniaceae and various bacteria. The coral's algal and bacterial communities can be shaped to varying degrees by environmental context. Sedimentation can structure a coral's microbial community by altering light availability for symbiotic algae, triggering the coral's stress response, or serving as a reservoir for both pathogenic and essential bacteria and algal symbionts. To examine the influence of sedimentation on a coral's microbial community, we used 16S rDNA and ITS-2 amplicon sequencing to characterize the bacterial and algal communities associated with the massive scleractinian coral *Porites lobata* across a naturally occurring sedimentation gradient in Fouha Bay, southern Guam. In addition to sedimentation, we are also investigating the relative contributions of other environmental parameters (i.e., temperature, salinity) to the coral's algal and bacterial communities and how these communities differ within a single colony (i.e., edge vs center). Along this gradient we see that sedimentation is higher and salinity and temperature are generally lower closer to the river mouth compared to the reef crest. Together these variations in environmental parameters play a strong structuring role in the coral's algal community and microbiome and these spatially structured communities may help corals thrive across this steep environmental gradient.

81-3 FIRNENO, TJ*; O'NEILL, JR; PORTIK, DM; EMERY, AH; TOWNSEND, JH; FUJITA, MK; University of Texas at Arlington, Arlington, Texas, Indiana University of Pennsylvania, Indiana, Pennsylvania, University of Arizona, Tucson, Arizona; *thomas.firneno@uta.edu*

Mitonuclear discordance Reveals Cryptic Genetic Diversity, Gene Flow, and a Complex Demographic History in a Problematic Complex of Mesoamerican Toads

Mitonuclear discordance can be caused by several evolutionary processes including incomplete lineage sorting, genetic polymorphism, and gene flow. Here we utilize the *Incilius coccifer* complex, a complex of three species (*I. coccifer*, *I. ibarrai*, and *I. porteri*) found throughout eastern Nuclear Central America that has had a history of taxonomic debate. By integrating mitochondrial DNA and nuclear loci from ddRADseq, along with comparative and integrative model testing, we have uncovered a more resolved population genetic structure amongst the three species that reflects the complex geography of the region, strong mitonuclear discordance between the lineages, and gene flow between populations of *I. poteri* within Honduras. We applied population clustering and phylogenetic inference to test hypotheses of population structure, as well as demographic analyses to test hypotheses related to population divergence and gene flow. Our results support the existence of three separate lineages within the complex, reflecting the current taxonomy; however, the lineage of *I. poteri* does not reflect the current recognized range of the species in Honduras. Our results also indicate the introgression within populations of *I. porteri* in central Honduras. Our results suggest that introgression and also divergence was most likely caused by range fluctuations due to past climatic instability.

18-7 FISCHER, EK*; PIERSON, E; PETRILLO, R; ELLIS, G; LAGERSTROM, KM; O'CONNELL, LA; Stanford University, Harvard University, Harvard University; *efisch@stanford.edu*

Tadpole Fight Club: Neural Mechanisms of Juvenile Aggression in Poison Frogs

Resource competition is a major driver of aggressive interactions among conspecifics, both at acute and evolutionary timescales. Aggressive interactions among siblings competing for resources is well documented; however, the mechanisms mediating juvenile aggression are poorly understood. In poison frogs, increased parental care is associated with decreased water volume of tadpole deposition sites resulting in increased resource competition and aggression. Indeed, the tadpoles of many poison frog species will attack, kill, and cannibalize other tadpoles. We examined the neural basis of conspecific aggression in *Dendrobates tinctorius poison frog tadpoles by comparing patterns of generalized neural activity as well as specific candidate molecules across tadpoles that won aggressive interactions, lost aggressive interactions, or did not engage in a fight. We found that distinct patterns of neural activity predicted whether individuals won or lost aggressive encounters. Increased activity of vasotocin neurons (the non-mammalian homologue of the nonapeptide arginine vasopressin) was associated with increased aggression. We further tested this association by characterizing the effect of vasotocin level manipulation on fight outcome. Given widespread functional conservation of the neural mechanisms underlying social behavior, we suggest that mechanisms mediating aggression in poison frog tadpoles may contribute to juvenile aggression across vertebrates.*

108-7 FISH, FE*; LEAHY, AM; KULKARNI, AA; LEFTWICH, MC; West Chester University, George Washington University, George Washington University; *ffish@wcupa.edu*

Hydrodynamics of a Crenelated Delta Wing Design of the Hindflippers of the California Sea Lion

The pectoral and pelvic appendages of the California sea lion (*Zalophus californianus*), like other pinnipeds, have been modified as flippers for movement in water. Unlike the foreflippers, which have a wing-like appearance and oscillatory movement for propulsion, the hindflippers are not used for thrust production in water, although the hindflippers are involved in terrestrial locomotion. The hindflippers are used as control surfaces for maneuvering underwater. When the digits of the flipper are abducted (spread), the hindflipper has a triangular planform. This design is similar to a highly swept delta wing. In addition, fleshy extensions of the digits provide a crenelated trailing edge to the flipper. To investigate its hydrodynamics, a hindflipper was spread and CT scanned to determine the three-dimensional geometry. Based on the CT scans, three models were printed: unmodified with crenelations, crenelations cut, and crenelations filled in. The lift and drag forces for each model was determined from flow tank testing at 1.0 and 1.5 m/s for angles of attack ranging from -25 to +25 deg. The lift coefficients with respect to angle of attack were similar for the three models and like delta wings they did not stall at highest angles of attack tested. The crenelated flipper had the higher maximum Lift/Drag ratios at higher positive and negative angles of attack compared to the modified flippers. The design of the hindflippers in sea lions as a delta wing with a crenelated trailing edge is useful for sea lions as a passive control surface at high angles of attack to execute sharp turning maneuvers.

44-4 FISHER II, AL*; DESJARDINS, N; DEGRANDI-HOFFMAN, G; SMITH, B; JOHNSON, M; KAFTANOGLU, O; COGELY, T; FEWELL, J; HARRISON, J; Arizona State University, United Stated Department of Agriculture - Agricultural Research Service; *afishe16@asu.edu*

A widely-used fungicide produces symptoms of colony collapse disorder in honey bees (Apis mellifera)

Honey bee (*Apis mellifera*) and other pollinator populations are declining worldwide for unexplained reasons, threatening over $12 billion in agriculture that depends on pollination services. Fungicides are applied to prevent rot diseases while many crop plants are in bloom, leading to wide consumption by pollinators. Field colonies of honey bees were forced to feed on pollen containing Pristine®, composed of the fungicides boscalid and pyraclostrobin, at four doses ranging from 0.1 to 100x levels previously reported for agricultural pollen. Pristine® consumption produced the symptoms of colony collapse disorder, reducing colony adult populations in a dose-dependent manner with foragers dying outside the hive, and reducing over-winter survival. Pristine® consumption lowered colony populations by causing workers to forage and die earlier. Pristine® consumption reduced forager associative learning abilities, potentially reducing pollination efficiency and contributing to "lost foragers." Pristine® increased colony pollen foraging and storage, suggesting it may act by interfering with protein digestion or absorption, perhaps by inhibiting intestinal mitochondria. Together, these findings suggest that fungicides play a significant role in pollinator decline and that the safety of fungicides for pollinators must be re-evaluated. This research was supported by USDA 2017-68004-26322.

26-6 FISSETTE, SD*; BUSSY, U; HUERTA, B; LI, W; Fisheries and Wildlife, Michigan State University, East Lansing, MI; *sdfissette@gmail.com*

Diel Pattern of Pheromone Production and Release in Sea Lamprey, Petromyzon marinus

During reproduction, it is vital for animals to coordinate the timing of behavioral and physiological cycles. The sea lamprey, *Petromyzon marinus*, relies on pheromone communication for reproduction. Sexually mature male sea lamprey release a multicomponent sex pheromone through their gills that attracts mates. Sea lamprey are primarily nocturnal, but it is unknown if male pheromone release is consistent with this behavioral pattern. We investigated if sea lamprey exhibit a diel pattern of pheromone release, and whether it is driven by biosynthetic production or is a byproduct of elevated respiration due to increased behavioral activity. We quantified pheromone release and production by measuring 3keto-petromyzonol sulfate (3kPZS, a main pheromone component) and its biosynthetic precursor petromyzonol sulfate (PZS) in holding water and tissue samples at 6 different times of day. Behavioral activity and respiration rates were measured using visual observations and video analysis. 3kPZS release exhibited a diel pattern with elevated release during nighttime hours. This pattern was disrupted by holding lamprey in constant darkness or light for 7 days. Trends in hepatic synthesis and circulatory transport of PZS and 3kPZS were consistent with 3kPZS release, whereas trends in respiration rates were less consistent. Our results suggest elevated levels of pheromone production and release at night evolved to match nocturnal increases in behavioral activity. Synchronizing these cycles may be imperative for reproductive success by ensuring reproduction occurs at optimal times, which is especially important in a species having a single, reproductive event.

113-1 FITAK, RR*; WHEELER, BR; NAISBETT-JONES, LC; SCANLAN, MM; NOAKES, DLG; JOHNSEN, S; University of Central Florida, Duke University, University of North Carolina, Oregon State University; *robert.fitak@ucf.edu*

Time-dependent Characterization of Candidate Magnetoreception Genes in the Brain of Chinook Salmon

Although numerous animals are known to use Earth's magnetic field for orientation and navigation, the underlying mechanism of this magnetic sense remains poorly understood. In trout, we previously showed that a magnetic pulse elicits gene expression changes in the brain, whereas this same pulse had little effect in the retina. This result suggested that the brain may be a possible location of a magnetoreceptor and that genes associated with iron regulation (e.g. *frim*) and the development and repair of photoreceptive structures (e.g. *crygm3, purp, crabp1*) are possibly associated with a magnetic sense. Further characterization of these candidate genes is necessary to understand their potential role in a magnetic sense. In this study, we examined changes in the expression of various candidate genes and those involved in iron regulation in the brain of Chinook salmon (*Oncorhynchus tshawytscha*) after exposure to the same magnetic pulse. We quantified gene expression relative to control fish across eight timepoints in a 48 h window (10 m, 30 m, 1 h, 3 h, 6 h, 12 h, and 24 h) using a novel, high-throughput gene counting technology. The results discussed provide important details regarding the potential role of cellular iron regulation and photoreceptive structures in the salmonid magnetic sense.

86-3 FLEMING, JML*; CARTER, AW; SHELDON, KS; University of Tennessee, Department of Ecology and Evolutionary Biology ; *jflemi17@vols.utk.edu*

Beetle Pupae Show Tradeoff Between Metabolic Depression and Body Size in Response to Increased Temperature Mean and Variance

Climate change is causing increases in temperature mean and variance. Organisms may respond to temperature changes during development, but few studies have examined physiology of early life stage as a mechanism to mediate the impacts of climate change. Using the dung beetle *Onthophagus taurus*, we investigated the potential of metabolic depression in an early life stage to buffer beetles from climate change. Specifically, we examined the effects of increasing temperature mean and variation on metabolism of pupae and fitness of adults using body size as a proxy. We reared beetles in nine incubation treatments using a full factorial design: three averages (22, 24, 26°C) and three fluctuations (±2, ±4, ±8°C) in temperature. At pupation, we measured thermal sensitivity of metabolism (TSM), the relationship between temperature and metabolic rate. We reared beetles to adulthood and measured body size. The relationship between temperature and metabolic rate was affected by developmental incubation; temperature mean and variation interact to influence pupae TSM (p= 0.002). Beetles reared in the warmest, most variable treatment exhibited significant metabolic depression across temperatures and significantly smaller body size. Thus, the reduction in energetic costs showed a tradeoff with body size. These findings suggest plasticity in early life stages can help beetles cope with thermal environments during development, but this may come at a cost to fitness later in life.

117-5 FLORKOWSKI, MF*; YORZINSKI, JL; Texas A&M University; *mflorkow@tamu.edu*

D2 Dopamine Receptor Activation Induces Aggression in Male House Sparrows (Passer domesticus)

Social species, including gregarious birds, often use aggressive interactions to secure resources and establish dominance hierarchies within their social groups. Dopamine is an important neurotransmitter that may play a role in regulating aggression, but we know surprisingly little about its effect on aggressive behaviors. In this study, we tested the hypothesis that D2 dopamine agonists and antagonists influence aggressive behavior in house sparrows (*Passer domesticus*), a social species that lives in groups throughout the year. We monitored the behaviors of pairs of captive male house sparrows before and after they were injected with D2 agonists, D2 antagonists, or controls. Preliminary analyses suggest that D2 dopamine agonists increase aggressive behavior while D2 dopamine antagonists suppresses aggressive behavior. The effects of the D2 dopamine agonists were most pronounced in birds with higher social status. The results of this study suggest that aggressive behaviors are regulated by dopaminergic pathways.

19-4 FONTAINE, SS*; KOHL, KD; University of Pittsburgh, PA; *ssf20@pitt.edu*

Temporal effects of temperature on tadpole gut microbial communities

Environmental temperature impacts all aspects of ectotherm physiology, and also alters the composition, diversity, and function of their gut microbial communities. Alterations to gut microbiota at high temperatures may result in negative consequences for host performance and survival. However, it is currently unknown how quickly the gut microbiota responds to changes in temperature. Here, we investigated the temporal effects of temperature on the gut microbiota of two tadpole species, the green frog, *Lithobates clamitans*, and the bullfrog, *L. catesbeiana*. We housed tadpoles in captivity, exposed half of the animals to a 5°C increase in temperature, and collected whole gut samples at six time points, ranging from 12 hours to 10 days, following the temperature change. We found host species-specific differences in microbial community response to temperature. Bullfrog-associated communities were altered within 12 hours, while those of the green frog took 4 days to exhibit significant changes. Temperature-induced alterations to gut microbiota could be mediated by host physiological factors, an idea supported by the fact that we observed no change in the environmental microbial communities of tank water. These results suggest that even short-term increases in environmental temperature, which may occur more frequently under global climate change, could result in changes to ectotherm gut microbiota.

128-1 FOQUET, B*; SONG, H; Texas A&M University; *Bert.Foquet@gmail.com*

Behavioral and molecular reaction norms of locust phase polyphenism in a phylogenetic frame work

Locusts are grasshoppers (Acrididae) that form large migratory swarms or marching bands, and show density-dependent phase polyphenism. This polyphenism consists of two phases, solitarious and gregarious, that manifest in response to low and high population density, respectively. The two phases differ in several traits, including but not limited to behavior, morphology, nymphal coloration, physiology and reproduction. From a phylogenetic perspective, locusts are rare among grasshoppers, representing only 19 out of about 6700 grasshopper species. They are a phylogenetically heterogenous group, strongly suggesting that density-dependent phase polyphenism in locusts convergently evolved multiple times. The genus *Schistocerca* contains three locust species and more than 40 non-swarming sedentary species, and the phylogeny of the genus is well understood. In this study, we focus on the Central American locust (*S. piceifrons*) and three closely related non-swarming grasshoppers that, together, are expected to form a spectrum in the degree of density-dependent phenotypic plasticity. We reared *S. piceifrons* and these three related species in isolated and crowded conditions, and subsequently quantified density-dependent reaction norms at a behavioral and a molecular level. We establish that there is indeed a spectrum of density-dependent phenotypic plasticity in this clade at both tested levels. We subsequently discovered clear correlations between gene expression patterns in our study system and behavioral traits using a weighted gene co-expression analysis. This represents the first study of locusts in a phylogenetic framework, and extends our understanding about the evolution of the density-dependent phase polyphenism.

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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 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 (14 species, n=40 specimens) and Mormyridae (6 species, n=30 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. Results indicate multiple instances of significantly convergent morphologies, both within and between the families. Several species are more morphologically similar to those in another family than to species within a family. These results invite further study into the roles of natural selection and developmental constraints in the production of convergent phenotypes.

120-7 FORD, MP*; SANTHANAKRISHNAN, A; Oklahoma State University; *askrish@okstate.edu*

Too close for comfort: importance of inter-appendage spacing in metachronal swimming performance

Metachronal paddling of multiple appendages is a swimming strategy used by many ecologically important marine species across a wide range of body sizes and Reynolds numbers. The appendages in metachronal paddling are stroked in an oscillatory pattern, with a phase lag between each neighboring appendage. The ratio of inter-appendage distance (D) to appendage length (L) has been previously reported to fall within the range of 0.2-0.65 for over 30 crustacean species, as well as one ctenophore species known to use metachronal paddling (Murphy et al., Mar. Biol., 158, 2011). Small inter-appendage spacing could allow for thrust augmentation through shear layer interaction in the fluid, while large inter-appendage spacing could effectively isolate appendages from each other. We developed a self-propelled metachronal swimming robot ("krillbot") in order to determine the effects of varying different physical and kinematic parameters on metachronal swimming performance. In this study, we use krillbot to investigate the effects of varying inter appendage spacing on thrust, swimming speed, and fluid dynamic characteristics of the wake. When kinematic parameters are maintained across varying inter-appendage spacing, decreasing spacing results in increased swimming speed. However, very small inter-appendage spacing restricts the possible kinematics parameter space, requiring either stroke amplitude or phase lag between adjacent appendages to be small to avoid collisions between neighboring appendages for a purely metachronal stroke pattern. Interestingly, animals with low D/L ratios (e.g., mantis shrimp, copepods) typically use their paddling appendages for rapid acceleration rather than routine swimming, performing a hybrid stroke consisting of a metachronal power stroke and nearly synchronous recovery.

57-6 FORLANO, PM; CUNY Brooklyn College, CUNY Graduate Center; *pforlano@brooklyn.cuny.edu*

Evidence for Monoamines as Neurochemical Substrates Underlying Alternative Reproductive Tactics

Species that exhibit alternative male reproductive tactics (ARTs) offer an outstanding opportunity to explore the neural and hormonal mechanisms that underlie often extreme divergence in brain and behavior within a sex. Plainfin midshipman fish, *Porichthys notatus, exemplify such male ART divergence in vocal courtship, territoriality and aggression with correspondingly dimorphic brain, somatic and hormonal phenotypes. Across vertebrates these behaviors are modulated by brain monoamines, which include serotonin (5-HT), and the catecholamines (CA) dopamine and noradrenaline. Focusing on discrete monoaminergic nuclei and the well-delineated intrasexually dimorphic vocal circuitry in this species, we investigated if brain monoamines provide additional neural substrates underlying divergence in reproductive behavior between male ARTs. Indeed, high 5-HT and low CA innervation in the vocal hindbrain is characteristic of the highly vocal, aggressive, territorial "type I" phenotype while the reverse pattern is seen in sneaker "type II" males, suggesting excitatory vs inhibitory action of 5-HT and CA, respectively, on vocal motor neuron output. In contrast, larger 5-HT-ir cell volume to body size ratio in type II males is consistent with a predictably higher serotonergic tone in the non-territorial, comparatively non-aggressive males. In addition, acoustic playback experiments coupled with markers for neuronal activation indicate both similarities and differences in CA responses between ARTs and suggests intrasexual divergence in social acoustic signal processing.*

94-4 FORSBURG, ZR; Texas State University; *frog@txstate.edu*

Effects of artificial light at night and predator presence on the development, growth, and physiology of Rana berlandieri

Artificial light at night (ALAN) alters the natural light dark patterns in ecosystems. ALAN can have a suite of effects on community structure and is a driver of evolutionary processes that influence a range of behavioral, developmental, and physiological traits. While ALAN has been shown to alter corticosterone levels of *Rana berlandieri* tadpoles in a previous laboratory reaction norm study, our understanding of how ALAN affects amphibians in natural environments is lacking, yet research is warranted as ALAN could contribute to stress and declines of amphibian populations, particularly in urban areas. Further, it is unknown if ALAN is interacting with natural environmental stressors such as predator presence. I tested the hypothesis that *Rana berlandieri* tadpoles exposed to ALAN or the presence of a common predator, dragonfly larvae, will be physiologically stressed and exposure to both ALAN & predators will have additive consequences on corticosterone production and survival. I reared tadpoles in outdoor mesocosms using a 2 X 2 randomized factorial design, with two predator treatments (presence or absence of one caged dragonfly larva), and two light treatments (natural light cycle control or constant ALAN from ~200 LUX LED lights). I measured corticosterone levels using a non-invasive water-borne hormone assay from the tadpoles after 7 and 14 days in treatments and continued to rear tadpoles in treatments until metamorphosis. I also measured and weighed individuals to track growth and development and recorded the date of metamorphosis for each individual. Findings from this study broaden our understanding of anthropogenic factors associated with amphibian declines and based on our current findings, mitigation of exposure to ALAN should be considered in management and conservation plans for amphibians.

33-2 FOSTER, S A*; BAKER, J A; Clark University; *sfoster@clarku.edu*

Plasticity and the Origin of Evolutionary Pattern

The role of phenotypic plasticity in evolution has become increasingly apparent in recent years. A primary recent interest has involved the possibility that it could guide evolutionary transitions and influence patterns of adaptive diversification, including the evolution of phenotypic novelties. Here we offer evidence that not only does plasticity influence evolution in these ways, but that it also can produce apparent evolutionary pattern that may in represent plastic loss of ancestral phenotypic expression in novel environments due to the disappearance of a requisite environmental trigger. Under these circumstances lack of expression is the novelty in adaptive radiations, yet, as long as the phenotype is still responsive to the environmental trigger it can be expressed if the environment reverts to ancestral conditions, with the ancestral trait appearing as a novelty. We offer evidence that the capacity to express plastic traits can be retained for thousands of generations, although in some cases, modified in pattern of expression or intensity of the environmental trigger required for expression. Distinguishing lack of expression, or evolutionary loss requires examination of multiple taxa in a radiation to correctly infer novelties versus ancestral traits and to understand transitions in plasticity over time and the possible roles of plasticity in evolutionary change. Such analyses can provide novel insights into the role of plasticity in evolution, but is exceptionally difficult as it requires a clear phylogenetic understanding of the group, understanding of the ecology of the species or populations, and the capacity to evaluate patterns and underlying genomics of plasticity in multiple populations or species.

66-4 FRANKLIN, CE; The University of Queensland; *c.franklin@uq.edu.au*

Unravelling the reptilian thermoregulatory paradigm

The thermoregulatory paradigm for reptiles is that they maintain some control over body temperature behaviourally through basking, shuttling between cool and hot microclimates and via changes in posture and position. Coupled with these behaviours are physiological mechanisms that facilitate thermoregulation, including cardiovascular control of heating and cooling rates. However reptiles have also been shown to maintain performance through thermal independence of physiological processes and by thermal plasticity (acclimation/acclimatisation) and so have a suite of mechanisms to deal with changing environmental temperatures. Using body temperature data from a long term (> 10 years) field study on free-ranging estuarine crocodiles the thermoregulatory paradigm of reptiles is being further elucidated and unravelled.

S3-11 FRASER, GJ*; THIERY , A; MARTIN, KJ; JAMES, K; COOPER, RL; HOWITT, C; JOHANSON, Z; University of Florida, Gainesville, King's College, London, University of Sheffield, Natural History Museum, London, University of Sheffield; *g.fraser@ufl.edu*

Dental EvoDevOmics: Novel and conserved gene expression in shark tooth development

Tooth development and subsequent dental regeneration is governed by highly conserved genetic mechanisms that are common to all toothed vertebrates. However, diversity in tooth patterning, shape and regenerative capacity is widespread. We focus on some of the most extreme forms of dental character divergence in fishes e.g. pufferfish and sharks, to appreciate the development of this diversity. We have established the shark as a model for tooth development and continued regeneration. We explore the dental transcriptome to uncover novel markers that suggest a deviation from the conserved norm of tooth development. We discovered a number of transcripts that are new to tooth development, involved in the unique and unrivalled capacity for continuous dental regeneration in sharks. We sequenced total transcripts associated with 5 distinct compartments of the shark dental lamina, an epithelial sheet from which all teeth are formed. These lamina compartments included (i) basi-hyal taste buds, (ii) the junction between taste-tooth fields, (iii) early stage developing teeth, (iv) later stage developing teeth and (v) the successional lamina, a terminal region of the dental lamina where new teeth are produced. Transcripts returned showed differentially expressed gene clusters highlighting distinct signatures associated with regeneration and stem cell niche identity. These data illuminate the unique characters of the shark dental lamina. Now we can extend our understanding of tooth regeneration more generally, and recognize how this process can become inactive, reducing regenerative ability, seen in many vertebrates.

99-5 FRASER, CJ*; HILL, EC; BUTLER, MA; University of Hawaii; *claire7@hawaii.edu*

Morphological Variation between Terrestrial and Semi-Aquatic Papuan Microhylid Frogs visualized through DiceCTs and Dissection

Papua New Guinea is home to the *Asterophryinae*, an unusually diverse clade of frogs that vary in lifestyle, ranging from burrowers to swimmers. We conducted a morphometric and diceCT study of jumping, hopping, and swimming specialists to determine whether variation in musculature varies with performance. Using morphometrics we characterized general patterns of morphological variation and through diceCT we explored any underlying differences in musculature which might be attributed to their habits. We iodine-stained specimens from three species: *A. palmipes*, *M. lateralis*, and *H. rufescens* to visualize their soft tissues and analyzed the scans using 3DSlicer. We verified diceCT results via gross dissection of 13 hindlimb muscles and the Achilles tendon, specifically focusing on the extensors, flexors, and modeled forces in the hindlimbs around the hip, knee, and ankle joints. We were able to visualize muscle fibers via diceCT and obtain morphological measurements typically obtained via gross dissection, while maintaining physiological positioning and preserving the individuals. For verification, these muscles were isolated through the dissection of the individual muscles, which were then photographed and measured through ImageJ. We discuss muscle and morphological differences key for jumpers, hoppers, or swimmers.

102-7 FRAZIER, AJ*; JENSEN, NR; YOUNG, SP; COOLEY-RIEDERS, CC; TODGHAM, AE; University of California, Davis, Kootenai Tribe of Idaho; *ajfrazier@ucdavis.edu*

Does a Cannibal Feeding Strategy Impart Differential Metabolic Performance in Young Burbot Lota lota?

The practice of mitigating cannibalism in aquaculture is an important focus for hatcheries seeking to maximize yield and has been maintained in hatcheries focusing on wild stock restoration. We hypothesize, however, that a cannibal feeding strategy may confer performance advantages over a non-cannibal feeding strategy. This study examined metabolic performance differences between cannibal and non-cannibal burbot, *Lota lota*, at the Twin River's Hatchery in Bonner's Ferry, Idaho, USA. After habitat alteration led to a functional extinction of burbot in the region, the Kootenai Tribe of Idaho's Twin River's Hatchery has played a leading role in the reestablishment and conservation of burbot in the Kootenai River, Idaho. We examined morphometric data (weight, length, and condition factor), whole animal resting metabolic rate (RMR), and the enzyme activity of lactate dehydrogenase (LDH), citrate synthase (CS), and 3-hydroxyacyl-CoA dehydrogenase (HOAD) to describe the baseline metabolic performance of cannibal and non-cannibal burbot. Taken together, our results demonstrated significant differences in the metabolic strategies of the feeding strategies, where cannibal burbot relied more heavily on carbohydrate metabolism and non-cannibal burbot relied more heavily on glycolytic and lipid metabolism. This study demonstrates the need to reevaluate the traditional practice of removing cannibal fish in conservation hatcheries, as it may not be the ideal strategy of raising the most robust individuals for release. When natural habitat conditions cannot be restored due to permanent habitat alteration, prioritizing release of higher performing individuals could help achieve conservation goals.

22-6 FREEMAN, AR*; OPHIR, AG; SHEEHAN, MJ; Cornell University; *arf86@cornell.edu*

Doing more with less: African giant pouched rats specialize in olfaction with a typical olfactory receptor repertoire

Rodents use their keen sense of smell to navigate their environment, find food and mates, recognize conspecifics, and avoid danger. Furthermore, rodents are described as having large olfactory receptor repertoires in order to support their specialization in olfactory behaviors. However, among rodents, relatively little work has documented the olfactory receptor repertoires outside of traditional rat and mouse laboratory models. We examined the composition of the olfactory receptor repertoire of the African giant pouched rat (*Cricetomys ansorgei*), a Muroid rodent distantly related to mice and rats. The pouched rat is notable as it has a relatively large cortex and large olfactory bulbs compared to sympatric rodents of a similar size. This anatomical elaboration of their olfactory system has been postulated to support their olfactory behavior, which includes their use as 'biodetectors' in applied olfactory tasks. We hypothesized that in addition to anatomical elaboration, the pouched rat would have an expanded olfactory receptor repertoire, to further support their olfactory behaviors. We identified 1145 functional olfactory genes and 260 pseudogenes in the pouched rat genome. This repertoire is similar in size and composition to mice and rats, but has several family-specific expansions. Whether these expansions provide the pouched rat a specialized ability to detect particular odors remains an open question. We also identified 99 orthologous genes conserved among four rodent species, and 167 genes conserved within Muroidea, suggesting a conserved Muroid-specific olfactory receptor repertoire. Our data suggest that the pouched rat is capable of a suite of specialized olfactory behaviors with a typical Muroid olfactory receptor repertoire.

84-3 FREYMILLER, GA*; SCHWANER, MJ; WHITFORD, MD; MCGOWAN, CP; HIGHAM, TE; CLARK, RW; San Diego State University, University of Idaho, University of California, Riverside; *gfreymil@gmail.com*

Determining the functional significance of bipedalism in heteromyid rodents through comparisons of morphology and performance

Bipedalism is a relatively unique mode of locomotion and it is often accompanied by specialized morphological features. Within rodents, the most well-supported hypothesis is that bipedalism initially evolved to enhance vertical jumping ability for predator evasion. In previous research, we found that kangaroo rats (*Dipodomys* spp.) are exceptional evaders when dodging rattlesnake strikes. However, few studies have directly compared the evasive abilities of bipedal and quadrupedal rodents, and those that have rely on indirect measures (e.g. predator diet studies) or focus on running ability rather than jumping ability. Thus, the hypothesis of predator avoidance has yet to be directly tested in an ecologically meaningful way. We used hind limb muscle dissections and field-based attack simulations to measure muscle morphology and jump performance for three kangaroo rat species and a quadrupedal heteromyid rodent, the desert pocket mouse (*Chaetodipus penicillatus*). Reaction time and take-off velocity significantly differed among the rodent species; interestingly, there was not a significant difference between pooled bipedal and quadrupedal rodents, with larger kangaroo rat species performing more similarly to the pocket mice than to smaller kangaroo rat species. We will combine our morphology and performance data to determine which aspects of the hind limb morphology contribute most to the observed differences in performance. These results will have implications for understanding the selective pressures that drove the evolution of bipedalism in small mammals.

10-7 FRIEDMAN, ST*; COLLYER, ML; PRICE, SA; WAINWRIGHT, PC; University of California Davis, Chatham University, Clemson University; *sarahtfried@gmail.com*

Divergent processes drive parallel evolution in marine and freshwater fishes

Investigating the patterns of evolutionary diversification is vital to understanding the processes governing the rich biodiversity of vertebrates. Habitat can provide ecological opportunity and serve as a catalyst for evolution, resulting in the unequal spread of phenotypic disparity across ecosystems. While both marine and freshwater environments harbor significant portions of fish diversity, they offer a particularly intriguing evolutionary juxtaposition. The different biogeographic and environmental factors between the two ecosystems can have substantial effects on morphological diversification. Yet, both environments offer similar opportunities for diversification within benthic, demersal, and pelagic regimes, which lineages have radiated into with consistent phenotypic trends. Here, we investigate whether the axis of body shape diversity within each of these habitats differs between fishes in marine and freshwater systems. Using specimens from the Smithsonian Museum, we developed a dataset of linear measurements capturing body shape in 2,200 freshwater and 3,300 marine teleost species. By comparing angles between the first principal components, we find that the fish body shapes in corresponding regimes have more similar primary axes of diversity than would be expected by chance, but that different processes are driving these parallel patterns in freshwater and marine environments. Marine diversification is generally phylogenetically constrained, which may indicate widespread phylogenetic niche conservatism. In contrast, ecological signal appears to overpower phylogenetic constraints in freshwater lineages. In spite of these divergent evolutionary processes, our findings imply that habitat imposes strong selective pressures, driving consistent patterns of evolutionary diversification on a global scale.

91-3 FRIESEN, CN*; HAN, J; YOUNG, RL; HOFMANN, HA; UT Austin; *caitlin.friesen@utexas.edu*

Using correlated patterns of behavioral and molecular variation to understand individual variation

Members of social groups often show tremendous variation that can be understood by classifying individuals according to their specific type or role within a group. Across diverse taxa, the molecular traits underlying social types or roles have been well-studied, but the molecular correlates of individual variation have been difficult to experimentally examine. Our research addresses this limitation by utilizing an integrative approach to quantify co-variance across behavioral and molecular traits in response to changing social conditions over time. Here, we examined naturalistic groups of the highly social African cichlid fish, *Astatotilapia burtoni*, to understand how patterns of behavioral and molecular traits contribute to individual variation across contexts. *A. burtoni* males are either bright, territorial, aggressive, and reproductively active (socially dominant, DOM) or dull, non-territorial, and reproductively suppressed (subordinate, SUB). We assayed behavior, physiology, and transcriptomes of key brain regions involved in social behavior before and after defined environmental, social, and physiological perturbations. Our results demonstrate 1) a strong relationship between patterns of space use, social behavior, and physiology that suggest novel DOM styles, 2) behavioral resilience and physiological flexibility in response to perturbations, and 3) complex variance structure at the molecular level. This research provides insight into the causes and consequences of individual variation across levels of organization that can give rise to consistent behavior over time and context.

98-1 FROLOVA, AD*; MIGLIETTA, MP; Texas A&M University at Galveston; *frolova.alexandra@outlook.com*

Environmental tolerance ranges and limits suggest differences in habitat preference and resilience to climate change among jellyfish (Class Scyphozoa) congeners in the Gulf of Mexico

Jellyfish are important components of marine foodwebs and form blooms that negatively impact human enterprise. Jellyfish of the genus *Aurelia* (Class Scyphozoa) are common bloom-formers in the Gulf of Mexico (GoM). *Aurelia* have a multi-modal lifecycle where the perennial polyp produces seasonal jellyfish. Tolerance limits for survival are crucial to understanding present jellyfish polyp distribution and how distribution may change in climate change scenarios. We sampled and barcoded two *Aurelia* jellyfish from the GoM and an *Aurelia* species native to Japan: *Aurelia* sp. 9, a possible new species found offshore (*Aurelia* sp. new) and the invasive *A. coerulea*. Using controlled laboratory experiments we determined the temperature and salinity tolerance limits for polyps of the three species. We find that *A.* sp. 9 and *A. coerulea* were tolerant of a broad range of temperatures and salinities, but differed in tolerance limits, suggesting potential differences in habitat and resilience to climate change. *A.* sp. 9 was most tolerant of high temperatures and low salinities, such as those found in the estuaries of the GoM. Summer high temperatures in the coastal GoM exceed the upper thermal tolerance limits of *A.* sp. new and *A. coerulea*. This confirms that *A.* sp. new is an offshore species and suggests that the coastal GoM may not be suitable for the invasive *A. coerulea*. Ocean temperature increase may negatively impact resident *Aurelia* species and deter *Aurelia coerulea* from invading the GoM. This is the first account of *Aurelia* sp. new and the first report of temperature and salinity ranges limits for *Aurelia* species.

S8-4 FU, Q; GART, SW; MITCHEL, TW; KIM, JS; CHIRIKJIAN, GS; LI, C*; Johns Hopkins University; *chen.li@jhu.edu*

Body lateral deformation and compliance help snakes and snake robots stably traverse large steps

Many snakes live in mountains and forests and traverse large obstacles comparable to their body size. Similarly, snake robots have the potential to traverse terrain with large obstacles like earthquake rubble and construction sites for search and rescue and structural examination. Although snake locomotion on flat surfaces is inherently stable, in such complex terrain, snakes must deform their body in three dimensions, during which maintaining stability becomes a challenge. Here, we review recent progress in our group in this problem. We studied how the generalist variable kingsnake traversed a large step as high as 40% body length. We developed a method to reconstruct continuous body 3-D motion (both position and orientation) from marker tracking. We discovered that the snake combined lateral body oscillation and cantilevering to traverse stably. The body sections below and above the step oscillated laterally on the surface, which provided not only propulsion but also roll stability as the body section in between cantilevered in the air to bridge the large height increase. To further understand stability principles, we developed a robotic snake with a similar gait as a physical model to study how traversal depended on step height and body compliance. As step height increased, the robot with a rigid body rolled and flipped over more often, leading to frequent failure. By contrast, the snake that had a compliant body rarely suffered this problem. Adding body compliance to the robot reduced its roll instability during traversal by improving body contact with the terrain. Besides advancing understanding of snake locomotion, our robot achieved traversal speeds surpassing most previous snake robots and approaching that of snakes, while maintaining high traversal probability on steps as large as 40% body length.

20-1 FUDICKAR, AM*; BREWER, DE; Indiana University; *afudickar@gmail.com*

Distance Matters: Experimental Test of the Influence of Avian Migration Distance on Readiness to Breed in Spring

Migration in birds often results in individuals dispersing over large geographic areas after the breeding season. Here we asked if within population variation in wintering latitude, conveyed via photoperiod, contributes to variation in timing of the seasonal activation of the reproductive axis. In response to increasing photoperiod in winter and spring, the avian reproductive axis becomes stimulated, resulting in a transition to reproduction. In late summer we captured male song sparrows (Melospiza melodia) from a breeding population in Indiana, USA (39.16°N, 86.53°W) and assigned them to one of two indoor aviaries under the natural photoperiod of the site of capture. In mid-October, when song sparrows migrate south, we shifted the photoperiod of one aviary to the natural photoperiod at the southern extent of their wintering range (27.95°N, 82.46°W), simulating autumn migration. From mid-October to mid-March, the photoperiods in both aviaries were adjusted to follow the natural seasonal progression of day length at the two latitudes. In mid-March, when song sparrows migrate back to their northern breeding grounds, we shifted the photoperiod of the migrant treatment back to the natural photoperiod at their breeding grounds, simulating spring migration. Once a week, beginning in February, we measured testosterone synthesis capacity using a gonadotropin-releasing-hormone (GnRH) challenge. Despite experiencing longer photoperiods during the winter, birds in the migrant treatment had lower testosterone in spring compared to birds that were exposed to the shorter northern photoperiods. Our results indicate that within population variation in migration distance contributes to variation in readiness to breed in early spring.

101-3 FUESS, LE*; WEBER, JN; STEINEL, NC; DEN HAAN, S; BOLNICK, DI; University of Connecticut, University of Alaska Anchorage, University of Massachusetts Lowell, University of Texas; *lefuess@gmail.com*

Transcriptomic analyses of Gasterosteus aculeatus parasite response reveal mechanisms of resistance

Host-parasite interactions are poorly understood, despite their effects on a range of ecological and evolutionary processes. Specifically, variation in host resistance and the evolution of this resistance is well studied from a theoretical standpoint, but understanding of associated cellular mechanisms is lacking. The three-spined stickleback, *Gasterosteus aculeatus*, is a particularly powerful model of the evolution of host resistance: populations of *G. aculeatus* vary considerably in their resistance to the cestode parasite, *Schistocephalus solidus*. Using transcriptional analyses of experimental infections, we investigated patterns of gene expression that underlay host-parasite dynamics and contribute to variation in host immune response. We examined general host response to infection and compared gene expression across three different cross types (F2s and respective backcrosses) generated from two populations of fish, one resistant and one susceptible. Our findings indicate that infection is associated with suppression of host immunity. Resistant populations may circumvent this suppression. Furthermore, comparison of crosses allowed for the identification of candidate genes that may contribute to observed resistance phenotypes. These findings advance our understanding of the dynamics and evolution of host-parasite interactions in the *G. aculeatus- S. solidus* system. Broadly, the findings presented here are an excellent case study of micro-evolution of immune responses within a population, and contribute to increased understanding of evolutionary immunology and host-parasite coevolutionary dynamics.

115-5 FUIMAN, LA*; WILLIAMS, TM; DAVIS, RW; University of Texas at Austin, University of California Santa Cruz, Texas A&M University - Galveston; *lee.fuiman@utexas.edu*

Underwater Navigation by Weddell Seals (Leptonychotes weddellii) in the Antarctic Fast-Ice Environment

Most activities of Weddell seals occur during dives that extend hundreds to thousands of meters in distance and require the seals to hold their breath for 20 minutes or more. In the fast-ice environment of Antarctica, holes in the ice where seals can surface to breathe are scarce. Consequently, seals must return to a previous breathing hole or locate a new one to avoid drowning; how they navigate underwater with such precision is not known. This study used field experiments to test multiple hypotheses concerning the sensory cues and tactics Weddell seals may employ to navigate underwater in this challenging environment, with special attention to their possible use of geomagnetic cues. An archival data logger was fitted to each of 10 adult seals, which were released at three locations that differed in the orientation of the geomagnetic field, and allowed to perform voluntary dives. Analysis of three dimensional dive tracks demonstrated that outbound paths of dives in a given direction progressively increased in distance from the breathing hole. Seals returned home from long distance dives on remarkably straight homeward paths, or they traveled directly to a frequented route then turned toward home, which is consistent piloting by landmarks. Seventy-five percent of the frequented routes were directly below known linear disturbances in the snow on the top of the sea ice, indicating that Weddell seals primarily used overhead visual cues (pilotage by landmarks and waypoints) to navigate under ice cover. They were able to do so during both daylight and surface twilight, presumably due to exceptional visual sensitivity in low light environments. We did not find evidence that seals used geomagnetic or hydrodynamic cues when returning to a breathing hole under these conditions.

136-3 FUNK, EC*; KURPIOS, NA; MCCUNE, AR; Cornell University; *ef347@cornell.edu*

Ventral-dorsal inversion of the air-filled organ (lungs, gas bladder) in vertebrates

Study of the origin of evolutionary novelties is central to understanding the history of life. With advancements in developmental genetics, we can investigate the genetic basis of evolutionary novelties and their subsequent transformations. The gas bladder, derived from lungs of the common ancestor of bony vertebrates, originated within ray-finned fishes and is important for efficient buoyancy control. As homologous organs, the gas bladder and lungs share many similarities; however, the defining difference between the two organs is the location of budding from the anterior foregut; gas bladders bud from the dorsal wall and lungs from the ventral wall. Therefore, we are investigating whether the inversion of budding location is paralleled by a ventral-to-dorsal inversion of gene expression patterns. To determine the genes involved in gas bladder development and their spatial expression, we used laser-capture microdissection to isolate dorsal and ventral foregut tissue from larval bowfin (*Amia calva*) at three key developmental stages and sequenced the tissue expression profiles. Bowfin are an early-diverging ray-finned fish that possess a dorsal gas bladder and therefore, are an ideal species to study early gas bladder evolution. We identified the genes differentially expressed between dorsal and ventral tissues, and from this set, we characterized when and where known mouse lung-regulatory genes are expressed and whether they exhibit an inverted pattern during gas bladder development compared to lung development. We found *Tbx5* and *Gata4*, both of which are involved in lung development, to have dorsoventrally restricted expression patterns. In particular, *Tbx5* is highly expressed in the dorsal mesoderm surrounding the gas bladder bud, whereas during mouse lung development, it is expressed in the ventral mesoderm.

7-5 FURZE, ME*; DRAKE, JE; WIESENBAUER, J; RICHTER, A; PENDALL, E; Harvard University and Yale University, State University of New York , University of Vienna, University of Vienna, Western Sydney University; *morganfurze@gmail.com*

Tracing Sugars Throughout Whole Trees Exposed to Climate Warming

Trees allocate carbon (C) from sources to sinks by way of a series of processes involving carbohydrate transport and utilization. Yet it is unclear how these dynamics will respond to a warmer world. We conducted a warming and pulse chase experiment on *Eucalyptus parramattensis* growing in a whole tree chamber system to test whether warming impacts C allocation by increasing the speed of carbohydrate dynamics. We pulse labelled large, field-grown trees with ^{13}C CO_2 to follow recently fixed C through aboveground and belowground organs by using compound specific isotope analysis of sugars. We then compared concentrations and mean residence times of individual sugars between ambient and warmed (+3°C) treatments. Trees dynamically allocated ^{13}C labelled sugars throughout the aboveground belowground continuum. However, we did not find a significant treatment effect on C dynamics, as sugar concentrations and mean residence times were not altered by warming. From the canopy to the root system, ^{13}C enrichment of sugars decreased, and mean residence times increased, reflecting dilution and mixing of recent photoassimilates with older reserves. Interestingly, the presence of raffinose in the phloem provides evidence for a polymer trap mechanism for phloem loading. Our results suggest that a locally endemic eucalypt was able to adjust its physiology to warming representative of future temperature predictions for Australia.

57-5 GABOR, CR*; ASPBURY, AS; UJHEGY, N; BóKONY, V; Texas State University, San Marcos, TX, USA, Plant Protection Institute Centre for Agricultural Research, Budapest, Hungary, Plant Protection Institute Centre for Agricultural Research, Budapest, Hungary; *gabor@txstate.edu*

Environmental Variation From Land Use Conversion Affects Stress in Tadpoles

Land conversion alters water quality variables in freshwater habitats and may have negative consequences on population health of aquatic organisms. Populations exposed to land use conversion may have different abilities to modulate their stress response and their ability to recover (resilience) from stressors. Glucocorticoids, such as corticosterone, play a role in modulation of the immune system, and the level of corticosterone can be used to assess the overall stress and health of their populations. We measured baseline, stress response, and resilience corticosterone release rates in common toad, *Bufo Bufo*, tadpoles from ponds in agricultural, urban, and rural habitats. We also reared eggs from the ponds in a common garden design and measured corticosterone in the developed tadpoles. We hypothesized that tadpole corticosterone release rates would differ between converted habitats and rural habitats. We found that corticosterone was highest in tadpoles from urban ponds and lower in rural and agricultural ponds. All populations showed a stress response and resilience indicating that they are not chronically stressed. The fitness consequences (body condition) to resilience and stress response varied across populations. Corticosterone release rates were repeatable, indicating the ability of this trait to respond to selection. Corticosterone was lower in tadpoles from mesocosms and did not differ by original land use type, suggesting that differences observed in the natural populations were primarily associated with environmental conditions.

28-5 GADDAM, MG*; SANTHANAKRISHNAN, A; Oklahoma State University; *askrish@okstate.edu*

Squishy suction pumps: pore water release by upside-down jellyfish

Cassiopea medusae (upside-down jellyfish) are observed in sheltered marine environments, with their bells resting on the substrate and oral arms directed towards sunlight. Unsteady pulsations of the bell are used to generate feeding and exchange currents, which are significant to these organisms as they inhabit areas with low background flow velocities (e.g., mangrove swamps, seagrass beds). We examine whether bell pulsations can generate sufficient force to release sediment-locked nutrients. 2D particle image velocimetry (PIV) and planar laser induced fluorescence (PLIF) measurements were conducted on *Cassiopea* individuals of varying bell diameters, under initially quiescent flow conditions in a laboratory aquarium. PLIF measurements showed release of fluorescent dye, initially located 2 cm below the substrate, into the water column. Dye concentration was larger in high-shear regions in the medusa-induced flow above the substrate. Starting vortices formed during bell contraction were broken into small-scale structures when the jet was directed through the oral arms. Smaller individuals with higher pulsing frequency showed closer placement of vortices generated from multiple pulsing cycles that aided in augmenting concentration flux. Larger medusae with lower pulsing frequency appear to benefit from the increased time scale for suspension feeding and mixing of released pore water, on account of their wider and slower jets. Our results suggest that bell pulsations of *Cassiopea* medusae can facilitate nutrient cycling and benthic-pelagic coupling.

S6-10 GALL, MD*; DE KONING, M; BEATINI, JR; PROUDFOOT, GA; Vassar College; *megall@vassar.edu*

Directional sensitivity of Northern saw-whet owls: implications for prey and wing sound detection

Many animals localize sound sources using cues derived from sounds arriving at two ears that are segregated in space. Animals can also localize sounds using monaural cues, such as location-based spectral or amplitude profiles. Spectral and amplitude profiles are thought to be generated by the soft tissue of the pinna in mammals and by soft tissue and the facial ruff in barn owls (*Tyto alba*). Asymmetry of ear placement in the skull, in addition to soft tissue asymmetry, is found in only a few species, such as the Northern saw-whet owls (*Aegolius acadicus*). We investigated the effect of spatial location on monaural responses in the Northern saw-whet owl, using auditory evoked potentials to measure the response of each ear to sound sources placed in different locations around the head. The response amplitude changed most dramatically with elevation and the response latency changed most dramatically with azimuth. Furthermore, we found that sensitivity was greatest in the spatial locations above the beak and in front of the head. Sensitivity dropped off dramatically as the sound source was moved behind the head. This directional sensitivity should improve sound detection and processing of prey cues in front of the head, while reducing the effect of noise generated during flight.

106-5 GAMBOA, M P*; KOHLRUSS, P S; WOLF, B O; SILLETT, T S; FUNK, W C; GHALAMBOR, C K; Colorado State University, University of New Mexico, Migratory Bird Center, Smithsonian Conservation Biology Institute; *mgamboa@rams.colostate.edu*

Climate variation facilitates morphological, not physiological, divergence in song sparrows

Divergent selection and limited gene flow across varying environments may lead to population differentiation at small spatial scales. On the California Channel Islands, song sparrows (Melospiza melodia graminea) occupy a steep climate gradient and exhibit low dispersal. Population genomic results suggest selection drives observed bill variation with larger bills found on hotter islands, consistent with hypotheses stating the avian bill is a thermoregulatory tool. However, the bill represents only a small proportion of the body capable of heat loss. Furthermore, how the relationship between thermogenesis, thermal conductance, and morphology varies between populations remains unknown. Here, we examine the relationship between (1) climate and feather microstructure and (2) climate and thermal physiology. Specifically, we quantified differences in breast contour feathers between island and mainland sparrows (M. m. heermanni) to infer insulatory ability. We coupled this with respirometry experiments to determine whether populations exhibit differences in metabolic rates and thermal limits. We found no significant difference among regions in physiological traits. Yet, we identified a significant difference in the proportion of the feather that was plumulaceous and evidence for greater barb density in birds from colder islands. Plumage results suggest birds on colder islands have better insulation, likely a plastic response to climate based on work in other species. Together, this suggests that populations may cope with climatic challenges by first modifying morphological characteristics before altering complex, physiological traits.

20-3 GARCIA, MJ*; TEETS, NM; University of Kentucky; *mjga237@uky.edu*

Genetic Variation and Molecular Regulation of Cold Hardiness in Spotted Wing Drosophila

Managing invasive pests requires a thorough understanding of their basic biology including life history traits, resistance to control treatments (e.g. pesticides), and thermal tolerance. Cold hardiness – ability to cope with low temperature stress – is a key mediator of insect geographic distribution and population structure and influences their ability to invade and establish in novel environments. Variation in cold hardiness within and among populations is driven by complex interactions between environmental and genetic factors and is regulated by multiple physiological and molecular mechanisms. The aim of this study is to leverage genetic variation across genetically distinct lineages of a globally invasive fruit pest, spotted wing drosophila (SWD; *Drosophila suzukii*), to identify key transcriptional regulators of cold hardiness. First discovered in CA in 2008, SWD has since spread to all 48 mainland states. Female SWD lay their eggs into ripening, soft-skinned fruits of economic importance, and subsequent larval feeding leads to product loss. We have generated isogenic SWD lineages derived from field populations along a North-South latitudinal gradient from Wisconsin to Florida. We measured acute cold shock survival, cold-induced deficits in fecundity, and critical thermal minimum temperature (CTmin) across all lineages. Current findings indicate significant variation among lineages for all cold hardiness measures assayed. In ongoing experiments, we will identify key transcriptional regulators of cold hardiness via RNA-seq. Results of this study will provide greater insights into the genetic mechanisms underlying variation in invasion-related traits in SWD and will contribute to improved modeling and control efforts.

8-8 GARDNER, SA*; AREVALO, L; CAMPBELL, P; University of California, Riverside, Oklahoma State University , University of California, Riverside ; *sgard014@ucr.edu*

Characterizing the placental microbiome in mouse (Mus) hybrids

The developmental environment, including the maternal microbiome (the community of symbiotic bacteria that regulates diverse host processes), can have a lasting effect on offspring phenotypes. In mammals, the microbiome was traditionally thought to establish in the postnatal period after exposure to the maternal vaginal tract. However, recent studies in mice suggest prenatal transfer of maternal microbes via the placenta. This prenatal inoculation is thought to promote the development of the mucosal immune system in offspring. While environment and diet play large roles in shaping microbiota composition, mounting evidence suggests that host genotype also plays an important role. However, the degree to which offspring genotype influences the composition of the prenatally-transferred community is unknown. To fill this gap we crossed two closely related mouse species, *Mus musculus domesticus* and *Mus spretus*. *M. m. domesticus* (n = 10), *M. spretus* (n = 11), and hybrid (n = 9) placentas were collected in late gestation at embryonic day 17.5. Microbial DNA was extracted and the V4 region of the 16S rRNA gene was sequenced for each placental genotype. If the composition of the placental microbiome depends only on maternal species, we should see no difference in community composition between hybrid placentas carried by *M. m. domesticus* mothers and *M. m. domesticus* placentas. If, however, offspring genotype plays a role in determining placental microbial composition, hybrid placentas should be distinct from both parental species. This project will provide a first step in understanding the impact of offspring genotype on microbial community composition during gestation.

50-5 GARNER, AM*; WILSON, MC; WRIGHT, C; RUSSELL, AP; NIEWIAROWSKI, PH; DHINOJWALA, A; University of Akron, University of Calgary; *amg149@zips.uakron.edu*

Adhesive Setal Morphology and Setal Field Configuration in Anolis equestris

Hundreds of studies have examined gecko adhesion in hopes of informing synthetic fibrillar adhesive design. Fibrillar adhesion, however, has convergently evolved in two other lineages of lizards (anoles and skinks), but comparatively fewer studies have investigated their adhesive pad morphology, function, and properties. This is particularly unexpected for *Anolis* lizards because they are considered to be model organisms for evolutionary ecology, and have been the subject of intensive biological study for several decades. Gecko ecology is relatively cryptic and understudied, but the vast literature detailing the relationships between *Anolis* morphology and habitat use may illuminate ecomorphological hypotheses for geckos. The adhesive setal field configuration has been described for several gecko species, and it appears that setal characters vary predictably along the proximodistal axis of their adhesive pads. *Anolis* setal field configuration remains largely unexplored and the only data available pertain to reports of the gross dimensions of a single seta. In this study, we examined setal morphology and setal field configuration of *Anolis equestris* and compared these data to those currently available for geckos. Overall, we found that the proximodistal variation in setal characters of *A. equestris* differs considerably from that of geckos, suggesting that setal form may be related to differences in peeling behavior. Our findings not only add to the existing comparative literature on the morphometrics and patterning of fibrillar adhesive systems, but also introduce *Anolis* lizards as an additional source of inspiration for bio-inspired synthetic adhesives.

S7-12 GARRETT, AD; BRENNAN, RS; STEINHART, A; PELLETIER, A; PESPENI, MH*; University of Vermont; *mpespeni@uvm.edu*

Linking Genome to Phenome for Complex Traits: Studies of Global Change Adaptive Variation in Marine Invertebrates

Variable environments can promote the maintenance of genetic variation that is adaptive in global change conditions. The genome of the purple sea urchin, *Strongylocentrotus purpuratus*, has adaptive variation that allows developing larvae to survive extreme ocean acidification conditions (pH 7.5), conditions periodically experienced in nature. However, little is known about adaptive responses to variable pH conditions or the genomic capacity to respond to future extreme low pH conditions (i.e., pH 7.0), beyond what has been experienced across space and evolutionary time. Here, we reared purple sea urchin larvae in static and variable, control and extreme acidification conditions (pH 8.1, 7.5, and 7.0) and measured survival, growth, and allele frequency shifts using pooled genomic DNA sequencing. We found decreased survival in extreme static pH conditions, with higher survival in variable conditions. In contrast, we found decreased total body length with decreasing pH, with extreme variable conditions causing the greatest decrease in larval growth. Together, these results suggest a potential tradeoff between survival and growth in extreme variable conditions. Genomic results showed consistent allele frequency shifts among replicate culture vessels with the greatest differences between pH treatments while static and variable pH treatments were most different at the lowest pH (7.0). Forthcoming analyses will reveal more about variation in the functional genetic mechanisms used to survive and grow in static versus variable and low versus extreme low pH conditions.

97-5 GARTNER, SM*; WHITLOW, KR; LAURENCE-CHASEN, JD; GRANATOSKY, MC; ROSS, RC; WESTNEAT, MW; University of Chicago, New York Institute of Technology; *sgartner@uchicago.edu*

Suction feeding of the African Lungfish, Protopterus annectens; XROMM analysis of jaw mechanics, cranial kinesis, and hyoid mobility in a novel feeding mechanism.

Lungfishes (Sarcopterygii:Dipnoi) use strong suction feeding to capture their prey and cyclic chewing to process their food. The skulls of living lungfishes show a substantial reduction in cranial bones compared to actinopterygians, yet still possess a more kinetic skull than extant tetrapods. Despite skull fusion in the feeding apparatus, suction feeding is proficient, suggesting that these animals have developed novel suction kinematics to obtain their prey. Using X-ray Reconstruction of Moving Morphology, we focused on the initial suction strike and determined relative movements of five bones—pterygoid (upper tooth plate), prearticular (lower tooth plate), left and right ceratohyal, and neurocranium—during prey capture in the West African Lungfish, *Protopterus annectens* (N=3 individuals, 15 strikes). Cranial elevation and pterygoid motion were minimal, with rapid lower jaw depression preceding the movement of the ceratohyal. The jaw joint is hinge-like, where the majority of the movement is restricted about the mediolateral axis. The left and right ceratohyals are extremely mobile, undergoing dorso-ventral depression, rotation in all three degrees of freedom, and some translation posteriorly, enabled by an unfused symphysis and no bony connection to the skull. Hyoid timing is highly variable relative to jaw opening and closing, indicating decoupled linkage mechanics for modulation of buccal expansion and suction generation. The lungfish skull exhibits an intermediate stage of kinetic mobility between actinopterygians and tetrapods, with extreme hyoid mobility. NSF DEB 1541547.

40-3 GASSLER, TR*; FLAMMANG, BE; New Jersey Institute of Technology; *trg22@njit.edu*

Animated "Foot" Control During Walking in Skates

Skates are cartilaginous, dorsoventrally-flattened benthic fishes comprising more than 240 species. Several species have been observed to use the anterior lobe of their pelvic fins to locomote in a walking-like behavior. This anterior lobe is separated into three distinct sections, similar to a femur, tibia/fibula, and foot, and has been previously likened to a tetrapod limb. A specific muscle, here named the distal radial retractor (DRR), appears to serve as an antagonist muscle of the protractor to provide stability and extend the crura or "foot". We believe this muscle to be an integral element for generating force during the walking behavior. A three-dimensional model obtained from a μCT scan of a little skate, *Leucoraja erinacea*, pelvic area was used in an animation software to interrogate this muscle. We created two models to look at presence/absence effect of the DRR. The first model included an active DRR while the second model did not. These models allowed for the definition and comparison of relative joint angles for both presence and absence of DRR activity during walking behaviors.

S1-8 GAST, RJ*; SANDERS, RW; Woods Hole Oceanographic Institution, Temple University; *rgast@whoi.edu*

You are what you eat: mixotrophic protists in Antarctic marine plankton communities

Despite the traditional view of protistan species as either phototrophic or heterotrophic, there are many photosynthetic protists that consume prey (mixotrophy). Some modeling studies suggest that mixotrophic activity will increase under warming scenarios and that they have the potential to dramatically alter the flow of nutrients in aquatic environments when compared with food webs dominated by strict autotrophs and heterotrophs. Mixotrophy is a widespread phenomenon in aquatic systems, but the factors known to induce this activity, including light limitation and micronutrient deficiencies, go through dramatic changes in the Southern Ocean. The contribution of mixotrophy is likely seasonal and linked to the taxonomic composition of the community. We have surveyed the presence and grazing impacts of mixotrophic phytoflagellates in Austral spring (2008), summer (2011) and late fall (2019). Our research indicates that these organisms can play a significant role as bacterivores in polar ecosystems, potentially consuming up to 100% of daily bacterial standing stock in the spring and comprising up to 75% of the grazing community in the summer. We have begun to use tracer studies of ingestion to identify unknown active mixotrophic species, quantification using qPCR, and transcriptome comparisons to better understand the taxonomic and functional diversities of the mixotrophic community.

133-8 GAU, JF*; LYNCH, J; GRAVISH, N; SPONBERG, S; Georgia Tech, UC San Diego; *jeff.gau@gatech.edu*

Asynchronous properties of synchronous hawkmoth flight muscles

Insect flight muscles have historically been divided into two distinct classes: synchronous muscles contract once per neural excitation while asynchronous muscles exhibit delayed stretch activation (SA) and shortening deactivation (SD) to produce power when cyclically stretched. However, SA and SD have been observed in synchronous vertebrate skeletal and cardiac muscle. Instead of distinct classes, we hypothesize that insect flight muscles exhibit a continuum of physiological properties. To address this hypothesis, we mounted synchronous *Manduca sexta* dorsolongitudinal muscles (DLMs) in a dual-mode muscle lever at 35°C. At tetanus, we stretched the muscle under *in vivo* conditions while measuring force output. Following a brief hold, we returned the muscle to rest length. Unlike prior work in synchronous locust flight muscle, we found significant SA characterized by a delay of 46 ± 2 ms (n = 7) and tension rise of 330 ± 110 mN (n = 7). Therefore, among flying insects, SA is not unique to asynchronous muscle. Temperature dependences on rise time are consistent with SA in asynchronous beetle and bumblebee muscle but a delay of one wingbeat period is significantly longer than that of the beetle. Despite antagonistic muscle arrangement and SA, *Manduca sexta* is a synchronous flyer because tonic Ca^{2+} is not present *in vivo* and SA may be too slow. Furthermore, we saw no evidence of SD, which may be necessary for asynchronous operation. This also suggests that SA and SD require different molecular machinery. In conclusion, we present asynchronous-like properties of synchronous flight muscle. Instead of distinct muscle classes, perhaps the synchronous and asynchronous operation of insect flight muscle is determined by their operating regime and a continuum of physiological properties.

111-1 GAWNE, R*; LEVIN, M; Tufts University; *richard.gawne@tufts.edu*
Planarian Head Shape Control: Regeneration Recapitulates Phylogeny
Planarian flatworms are important model systems for understanding regeneration because many species are able to reconstitute their entire body from small tissue fragments. Contemporary research on these animals has tended to focus on the mechanisms responsible for establishing head/tail polarity, and accordingly, we know a great deal about the factors that determine which end of a wounded body fragment will regenerate a head, as opposed to a tail. Comparatively little is known about how head shape is established, and why regeneration ceases when a specific head shape is achieved. The shapes of planarian heads vary significantly across species, ranging from rounded, to triangular, to square-like, and often change significantly over the course of regeneration. Using techniques from geometric morphometrics, we construct a morphospace for planaria head shapes, and show that species with complex head morphologies go through regenerative stages that resemble the fully formed heads of other species. In light of these, and other findings, we suggest that complex head shapes have evolved by a process of terminal addition. To better obtain a better understanding of how head shape is produced during regeneration, we experimentally inhibited cell-cell communication through the application of a gap junction blocker. This treatment was found to have different effects on the regenerative process in different species, indicating a potential role for non-genetic physiological mechanisms in the evolution of head shape.

S6-11 GóMEZ-BAHAMóN, V*; WORM, A; CASTAñO, M; DONAHUE, E; TUERO, D; CLARK, C; BATES, J; University of Illinois, Arkansas State University, Universidad de los Andes, Universidad de Buenos Aires, University of California Riverside, Field Museum; *vgomez21@uic.edu*
Non-vocal Acoustic Signals in Kingbirds (genus Tyrannus)
Many birds have evolved sonations (non-vocal acoustic signals) produced with tail or wing feathers. Within the family Tyrannidae 20% of the species have males with modified wing feathers hypothesized to produce sonations. Kingbirds encompass thirteen species, twelve with different outer primary feather modifications. The questions that this project aims to address are whether non-vocal signals in Kingbirds differ in 1 Acoustic characteristics, 2 The mechanism by which the sound is produced, and 3 The behavioral context. To answer these questions we compared high speed videos and sound recordings of displays in five species of Kingbirds: Eastern, Western and Tropical Kingbirds (T.tyrannus; T.verticalis; T.melancholicus) and Scissor-tailed and Fork-tailed Flycatchers (T.forficatus;T.savana). All species produced these sounds when increasing wingbeat frequency. The sound is produced by males when birds are close to each other during female-male interactions and male-male aggressive displays. In T.savana and T.forficatus the sound is also audible during interspecific aggressive attacks (e.g., against predators). Comparisons among two subspecies of T.savana showed differences in frequency during displays. Individual feathers in a wind tunnel over a range of airspeeds showed that the feathers of T.s.monachus produce sounds at a lower frequencies than those of T.s.savana matching those taken from field recordings. High speed videos of individual feathers in the wind tunnel suggest feathers make sound by fluttering of the trailing vane at the tip of the feather. We conclude that the mechanisms of sound production are similar between species of Kingbirds but that they differ in acoustic characteristics (such as frequency, intensity and duration).

118-6 GóMEZ-BAHAMóN, V*; CHEN, E; ASSIS, M; HEMING, N; MARINI, M; TUERO, D; BATES, J; University of Illinois , Field Museum , University of Brasília, University of Brasília, Universidad de Buenos Aires, Field Museum; *vgomez21@uic.edu*
Egg Shape and Flight Capacity in Birds Implementing a Novel Geometric Model
Among amniotic animals, birds evolved a variety of egg shapes. Two mayor types of hypotheses have been proposed to explain the morphologic diversity of this key avian feature: 1 adaptive hypotheses, which include life history pressures and breeding ecology as major drivers of egg shape, and 2 an indirect hypothesis, stating that egg shape evolves in correlation with skeletal and muscular features because of the physical pressures they exert during egg formation. The latter has recently been backed by evidence showing that at broad taxonomic scales, egg shape is associated with flight capacity, arguing that species with an aerial lifestyle have skeletal and muscular adaptations that differ from those of birds that spend more time on the ground. Studies that test adaptive hypotheses at the intraspecific level have focused on species with highly asymmetric eggs and that nest in cliffs, for which shape adaptations are clearly important. We test the hypothesis of egg shape evolving in association with flight capacity between closely related species and at the intraspecific level. Numerous species of birds have populations that are migratory and others that are sedentary, two behavioral strategies that have been shown to result in differences in wing shape across different families of birds. To test whether egg shape evolves in correlation with flight capacity, we studied egg shape within species of Kingbirds (Tyrannus) that have migratory and sedentary birds. We also developed a novel mathematical description of egg geometry and a computer app to measure egg shape. We find that eggs from migratory individuals are more elongated as was found at higher taxonomic levels, but that eggs from sedentary species are more asymmetrical, contrasting higher taxonomic trends.

122-7 GüELL, BA*; CALDWELL, MS; WARKENTIN, KM; Boston University, Gettysburg College; *bguell@bu.edu*
Treefrog egg-clutch biomechanics and their effect on embryo escape-hatching behavior
Arboreal embryos of phyllomedusid treefrogs hatch prematurely to escape snake predation, cued by low frequency vibrations in their egg clutches. Escape success varies between species, from 80% at 1d premature in *Agalychnis callidryas* to just 11% in *A. spurrelli*. However, both species begin responding to snake attacks at the onset of vestibular function. Egg clutches of *A. callidryas* are thick and gelatinous, while *A. spurrelli* clutches are thinner and stiffer, affecting whole-clutch and individual-egg movements excited by attacks. Since all vibration cues embryos perceive must propagate through their egg clutches, we hypothesized that differences in the hatching responses to snake attacks in *A. callidryas* and *A. spurrelli* are due to the influence of clutch biomechanics on the cues available to embryos. We tested this by embedding egg-sized accelerometers within clutches of both species and performing three standardized excitation tests at varying distances to the accelerometer: pendulum impacts, water droplets, and simulated snake-attacks. Mechanically, thinner egg clutches should have higher resonant frequencies, greater spatial attenuation, and damp more quickly than thicker, more flexible clutches. Initial analyses of clutch free vibrations following impact tests indicate *A. spurrelli* clutches oscillate at much higher frequencies than those of *A. callidryas*. *A. spurrelli* clutches also show greater differences in peak amplitudes between impact distances and faster attenuation of vibrations than *A. callidryas* clutches. Vibrations induced by water droplets and simulated snake-attacks also appear to differ between species. Vibration biomechanics may constrain the information available to *A. spurrelli* embryos and contribute to inter-species differences in hatching responses to predator attacks.

76-8 GECELTER, R*; KIKEL, M; THOMPSON, N/E; NYIT College of Osteopathic Medicine; *rgecelte@nyit.edu*

Hip Moments and Muscle Activity During Compensatory Osteoarthritis Gaits

Hip osteoarthritis (OA) is one of the most common joint diseases. This disorder causes OA patients to alter their gait to compensate for hip pain while maintaining frontal plane balance during walking. These compensatory gaits are likely an attempt to minimize hip abduction moment and/or muscle force. However, different compensatory characteristics exist among hip OA patients, particularly in pelvic motion, step width and muscle activity. Here we investigated the hip biomechanics underlying two compensatory gaits of hip OA: exaggerated pelvic drop and pelvic elevation on the swing side. We recorded full-body kinematics, kinetics and muscle activity in 9 subjects during normal and simulated pathological gaits. Kinematics were recorded via a 12-camera Vicon motion capture system using the Plug-In gait marker set. Subjects walked on an AMTI force-instrumented treadmill at 1.0 m/s under varying pelvic motions (normal, pelvic drop, pelvic elevation). Gluteus medius muscle activity was recorded using a Noraxon surface electromyography system. Compared to normal walking, exaggerated pelvic drop on the swing side entailed an increase in maximum hip abduction moment (~35%). Exaggerated pelvic drop on the swing side also elicited an increase in maximum stance-phase gluteus medius activity in our subjects. On the other hand, pelvic elevation resulted in a decrease in maximum hip abduction moment (~13%) though was accompanied by an increase in step width (~25%) and the highest increase in stance-phase gluteus medius muscle activity (~80%). Our results indicate that different OA gaits may optimize different gait characteristics. Pelvic elevation may be used when prioritizing hip abduction moment minimization, while exaggerated pelvic drop may be a solution to lower gluteal muscle force.

87-3 GEMILERE, R*; LDS-VIP, ; GAU, JF; SPONBERG, S; Georgia Tech; *rgemilere3@gatech.edu*

Wingbeat frequency modulation to large lateral perturbations in hawkmoths

Like many synchronous and asynchronous flying insects, steady flight in *Manduca sexta* typically occurs in a narrow band of wingbeat frequencies. However context can modulate this range. Artificial reduction of wing inertia causes a compensatory increase in wingbeat frequency of roughly 10%. Similarly, load lifting experiments increased wingbeat frequency by 20%. These results highlight the capacity for *Manduca sexta* to change wingbeat frequency to compensate for steady state changes in flight requirements. We hypothesize that *Manduca sexta* might also utilize rapid wingbeat frequency modulation to recover from large transient perturbations. To address this hypothesis, we recorded high speed video of hawkmoth flight at 2000 fps (n = 7). After each moth established stable hovering to feed in front of an artificial flower, we perturbed their flight by shooting the moths laterally with vortex rings. We estimated instantenous phase and wingbeat frequency via a Hilbert transformation on wing kinematics. Prior to the perturbation, the moths had an average wingbeat frequency of 24.7 +/- 1.4 Hz. In comparison, average wingbeat frequency over ten wingbeats during perturbation and recovery was 21.5 +/- 6.4 Hz. Although we found no change in mean wingbeat frequency ($p = 0.25$), there was a substantial increase in wingbeat frequency modulation. Pre perturbation, the frequency range was 2.6 +/- 1.0 Hz, which increased to 16.2 +/- 3.9 Hz post perturbation ($p < 0.01$). This range corresponds to roughly 65% of average wingbeat frequency. Furthermore, EMG recordings of the downstroke flight muscles corroborate that changes in wingbeat frequency are driven by changes in neural stimulation rate . These results suggest that synchronous flying insects may have wide control affordance in frequency when challenged with extreme conditions.

135-5 GEORGADARELLIS, GL*; JIMÉNEZ, JM; ALBERTSON, RC; University of Massachusetts, Amherst; *ggeorgad@umass.edu*

Increased Swimming Speed Induces Differential Bone Remodeling in Zebrafish

To better understand how dynamic loading plays a role in zebrafish (*Danio rerio*) bone development and growth, we have designed, built, and characterized a water tunnel. Boundary layer theory was used to design the water channel contraction ensuring thin boundary layers constrained to the near-wall, yielding a uniform flow field for the fish to swim in. Furthermore, turbulent flow theory was used to ensure an isotropic and homogeneous flow field void of velocity gradients. Our design encouraged fish to swim for the duration of the experiment, which is not the case for other swim chambers where fish have been observed to rest on walls to avoid swimming. Thus, we are able to investigate the role of increased swimming speeds on zebrafish bone remodeling in a well-defined flow field. Starting ~30 days post fertilization (dpf), sibling zebrafish groups were either exposed to an exercise regimen starting at a velocity of 1 body length per second (BL/s) for 6hrs/day for 7 days, or maintained in a standard 2.8-L tank of comparable water volume. The velocity was increased in the exercise group by ~10% each day. We noted structural differences between groups in the skeletal architecture of several functional units, including the caudal fin and pectoral apparatus. To determine the role of the Hedgehog (Hh) signaling pathway on bone due to exercise-induced mechanical load, we used two different transgenic fish wherein Hh levels can be up- or down-regulated in a time-specific manner. These experiments revealed a strong gene-by-environment effect, confirming that the Hh pathway is mechanically sensitive with respect to bone formation. Overall, our results provide a better understanding of how mechanical forces affect skeletal remodeling as well as the molecular genetic mechanisms that regulate this process.

95-4 GEORGE, EM*; ROSVALL, KA; Indiana University Bloomington; *georgee@indiana.edu*

How social challenges modulate steroid signaling in the female brain

Little is known about the mechanisms underlying female-female aggression, despite increasing evidence of its adaptiveness in many species. While some male vertebrates socially modulate circulating testosterone (T) levels after aggressive interactions, the same hormonal response has not been found in many female vertebrates, perhaps because selection has favored mechanisms that minimize the potentially high costs of elevated T levels in females. We hypothesize that, rather than changing *systemic* T levels in response to competitive interactions, females instead modulate *local* sex steroid sensitivity and conversion, i.e. by upregulating sex steroid receptors and steroid-modifying enzymes in behaviorally relevant tissues like the brain. Here we tested this hypothesis in tree swallows (*Tachycineta bicolor*), a species in which females compete for limited nesting sites and aggression is at least partially mediated by androgens. We found that females do not rapidly increase, and actually decrease, T levels after both real and simulated social challenges. In light of this result, we further explored whether social challenges induce changes in local steroid processing and binding within the brain. To test this, we exposed females to simulated territorial intrusions and collected neural tissue 2-3 hours later. We used qPCR to measure the expression of genes involved in steroid binding and processing in brain regions thought to mediate aggression, including nodes of the vertebrate social behavior network. These findings will provide novel insight into mechanisms by which individuals can respond to social challenges without increasing T production.

50-3 GEORGE, AB*; WESTNEAT, MW; University of Chicago; *abgeorge@uchicago.edu*

Swimming Performance Informs Patterns of Evolutionary Ecomorphology Among Triggerfishes and Filefishes (Superfamily: Balistoidea)

Triggerfishes and filefishes (superfamily Balistoidea) exhibit a wide range of morphological diversity including median fins that lie on a continuum from high to low aspect ratio. High aspect ratio median fins are associated with increased balistoid endurance swimming performance, while low aspect ratio fins likely facilitate short bursts of speed. We predicted that links between morphology and swimming performance could explain patterns of balistoid fishes convergently colonizing marine habitats from coral reefs to the open ocean and evolving planktivorous, grazing and predatory feeding modes. We hypothesized that balistoid species with high aspect ratio fins are associated with open water habitats and planktivory, ecologies requiring endurance swimming. Conversely, we predicted that fishes with low aspect ratio fins are associated with reefs and benthic grazing, ecologies requiring quick bursts of speed. To test these hypotheses, we calculated fin aspect ratios and conducted geometric morphometric analyses of fin and body shapes of 450 individuals representing 80 balistoid species and classified each species by primary habitat use and feeding mode. Ancestral state reconstructions revealed multiple convergence events on both high and low aspect ratio fins. We discovered multiple ecomorphology relationships such as reef-associated filefishes converging on deep bodies and low aspect ratio fins (Wheatsheaf index = 1.79, P = 0.023). The use of swimming performance to inform the interpretation of our ecomorphology results demonstrates the importance of combining functional and ecological research to thoroughly explore how and why species evolve novel morphologies and ecologies. Funded by NSF GRFP 1144082 and 1746045, IOS 1425049 and DEB 1541547.

127-2 GERMEROTH, LM*; SUMNICHT, TP; VERBLE, RM; Missouri University of Science and Technology, Rolla, MO; *lgm9d@mst.edu*

Maintaining Biodiversity of Ant Communities in the Crocker Range, Malaysian Borneo

Borneo is home to 1/16th of the world's ant diversity; however, intensive land use and agricultural practices are destroying forests at an accelerating pace. In 2014, UNESCO designated the Crocker Range as a Man and Biosphere region, which restricted development in core forests entirely and minimized development and impacts in surrounding buffer forests. We examined the efficacy of these zones in maintaining leaf litter ant biodiversity core and buffer highland rainforests in Summer 2019. We sampled leaf litter ant communities at twelve sites (N = 6 buffer; N = 6 core). Each grid was separated by > 50 m and consisted of 16 one-meter quadrats. Leaf litter was sifted using leaf litter extractors and then hung in Berlese funnels for 48 hours. Extracted ants were stored in ethanol, point mounted, and identified to genus using local taxonomic keys. Ant biodiversity in core and buffer forests was similar, and ant activity was highest in buffer forests. Species richness among sites was patchy. Our data support the continued use of zone stratification in these forests as an effective means of maintaining biodiversity reserves.

12-5 GIBSON, JD*; BOTNARU, L; COBB, BA; Georgia Southern University; *jgibson@georgiasouthern.edu*

Mortality and Physiology of Nasonia Hybrids

Nasonia is a genus with four species of parasitoid wasp that can be crossed in the laboratory, producing hybrids that demonstrate varying levels of reproductive isolation between these species. Previous work has shown that F2 hybrid males of crosses between *Nasonia vitripennis* and *N. giraulti* suffer >90% mortality during development when their genotype (*N. vitripennis* or *N. giraulti*) at a single nuclear locus doesn't match their mitochondrial genotype. Due to this pattern of mismatched nuclear and mitochondrial genotypes, we have hypothesized that the mortality is due to deficiencies in metabolic physiology. Unfortunately, the small number of surviving hybrids makes it difficult to assess experimentally any potential mechanisms of this mortality. All male Hymenoptera are haploid so any effect of dosage cannot be measure, however F1 female hybrids (diploids that are heterozygous for each species' alleles) don't suffer this mortality. Despite this, preliminary data on F1 females indicates that they have a lower mitochondrial O2 consumption rate than either parent species. We will present mortality and physiological data based on crosses of these two species in which we generate female F1 hybrids and F2 backcross hybrids that are either heterozygous or homozygous for the mortality inducing genotype. This initial data will allow us to begin dissecting the mechanism of hybrid mortality in *Nasonia* and may provide a more tractable experimental system for studying mitochondrial physiology in these hybrids.

116-3 GIFFORD, ME*; ROBINSON, CD; University of Central Arkansas, University of Virginia; *megifford@uca.edu*

T3 as a source of hormonally-mediated maternal effects in a lizard

Maternal effects are important mechanisms generating phenotypic variation in offspring with potentially adaptive consequences. Prenatal maternal effects often are mediated through maternal transmission of hormones to the developing embryo. Such effects are particularly well-studied in response to maternally derived steroid hormones. Thyroid hormones (TH), triiodothyronine (T3) and thyroxine (T4), are metabolic hormones having pleiotropic effects across several different life stages. During vertebrate development, THs are critically important for normal development, growth, and metabolism. Recently maternally-derived THs have been shown to vary among individual birds in association with some environmental characteristics including ambient temperature and reproductive timing, and among eggs within a single clutch. Therefore, although data are limited, the possibility exists that maternally-derived THs represent another mode through which adaptive plasticity could arise in offspring. Currently very few studies have examined the potential role of THs in regulating offspring phenotypes; and all studies to date have involved two taxa (birds and turtles) and even fewer have examined such effects in wild animals. We manipulated T3 concentration in eggs of the Prairie Lizard to test for variation in embryonic and hatchling phenotypes potentially related to fitness. T3 manipulation doesn't appear to dramatically affect embryonic traits but causes sex-specific responses in several hatchling phenotypes potentially related to fitness. In addition, hatchling phenotypes show dose-specific responses. In all, it appears that maternally derived THs can potentially serve as a source of adaptive plasticity in lizards.

69-6 GIGLIO, EM*; TRIPP, JA; PHELPS, SM; University of Texas at Austin; *eringiglio@gmail.com*

The role of leptin in social signal decisionmaking in neotropical singing mice (Scotinomys teguina)

Sexual signals are spectacular behaviors. Reproductive rewards for successful display are great, but must be balanced against the many potential costs. To maximize payoff, individuals must monitor both internal and external cues and use that information to adjust display investment. Leptin, a hormone secreted by adipose tissue, is a promising index of body condition that regulates energy allocation to functions as diverse as feeding, sleep, reproductive effort, and immune response. Despite evidence that leptin influences reproductive trade-offs, its role as a putative regulator of courtship display is poorly understood. Here we examine the integration of interoceptive and exteroceptive cues into allocations of display effort using Alston's singing mouse (Scotinomys teguina). We first manipulate individuals' perception of energy balance through intraperitoneal injection of exogenous leptin, and alter social context through playback of conspecific song using a repeated-measures design. Mice injected with leptin sing back more frequently and more quickly than mice injected with saline. Leptin also improved measures based on acoustic parameters thought to be indications of song effort, but not those thought to be markers of identity. In a follow-up experiment using a design that avoided some confounds of our repeated-measures design, we again found that animals injected with leptin sang at a high rate. We are currently examining the acoustic structure of evoked song, and the induction of immediate early genes in brain regions we hypothesize are responsible for integrating social context and body condition.

106-2 GILBERT, AL*; RUTSCHMANN, A; FITSCHEN-BROWN, MS; MILES, DB; CLOBERT, J; Ohio University, University of Auckland, tion of Experimental and Theoretical Ecology, Moulis, France; *anthony.gilbert09@gmail.com*

Acclimation to warmer temperatures attenuates heat-shock plasticity in high elevation populations of common lizards

As the intensity of heat waves and the occurrence of extreme weather patterns increases, ectotherms are likely to rely on heat-shock responses to counteract rapidly warming body temperatures and reduce the costs associated with heat stress. While heat shock responses tend to be conserved across taxa, the plasticity of these responses to increasing environmental temperatures is unknown. If warmer environmental temperatures reduce the strength of heat-shock responses, then the reliance on these plastic responses as a short-term mechanism of lethal temperature avoidance could dwindle as the climate warms. Here, we performed an experiment using five populations of common lizards (Zootoca vivipara) distributed along an elevational gradient to test how heat-shock responses (i.e. heat-hardening) change with acclimation to warmer environmental conditions. We measured cold tolerance (CTmin), preferred body temperatures (Tpref), heat tolerance (CTmax) and the heat-hardening response (the change in CTmax with heat shock) before and after acclimation to temperatures 2C above mean environmental conditions. We found that the strength of the hardening response was attenuated for populations at higher elevations, but not for populations at low elevations. Acclimation also shifted baseline heat and cold tolerances as well as preferred temperatures. These finding suggests that consistent and slow increases in environmental temperatures might over time reduce the ability of populations to mount short-term responses to rapid environmental changes.

122-1 GIGNAC, PM*; KLEY, NJ; Oklahoma State University Center for Health Sciences, Stony Brook University; *paul.gignac@okstate.edu*

At the nexus of iodine staining duration and specimen size: repeated-measures study to improve visualization of vertebrate soft-tissue anatomy using diceCT imaging

Diffusible iodine-based contrast-enhanced computed tomography (diceCT) facilitates three-dimensional imaging of soft-tissue anatomy at high spatial resolutions, relatively rapidly, and at manageable expense. A critical preparatory step is identifying the length of time for which a specimen should stain in iodine potassium-iodide (I_2KI) to (1) ensure the contrast agent fully penetrates the deepest tissues, but (2) without over-staining the sample thus reducing inter-tissue contrast differences and/or contributing to soft-tissue distortions. Finding this balance includes accounting for confounding factors such as size and iodine concentration. Here we designed a 780-sample repeated-measures analysis, using pairwise grayscale differentials to systematically document and analyze the effects of these variables. We used thick (~10 mm) sections from the bodies of adult specimens of pythons (*Liasis, Antaresia*) to represent standard samples of vertebrate tissues (e.g., cortical bone, spinal gray and white matter, skeletal muscle). Four size classes based on section diameter (~10, 20, 30, and 40 mm) were prepared in triplicate. Triplicates were stained with a series of exposures to I_2KI (1, 3, 5, and 10% concentrations) and at specific durations (7, 14, 21, 28, and 35 days), followed by µCT scanning to measure tissue grayscale values and total depth of staining within sections. Based on staining completeness and tissue differentiation, we generally found that longer staining durations produce the best results. However, acceptable contrasts can certainly be achieved using shorter staining periods at higher concentrations. We summarize the scope of our findings into best-practices recommendations for the diceCT community.

121-4 GILLEN, CM*; PIERMARINI, PM; ROMERO, MF; Kenyon College, Gambier, OH, The Ohio State University, Mayo Clinic, Rochester, MN; *gillenc@kenyon.edu*

Electrogenic Sodium Transport by Insect Cation-Chloride Cotransporters?

Cation-chloride cotransporters (CCCs) regulate cell volume and intracellular chloride and contribute to transepithelial salt secretion and absorption. CCCs include the K-Cl, Na-Cl, and Na-K-Cl cotransporters, which move monovalent cations and chloride in electroneutral fashion. The *Aedes aegypti* transporter aeCCC2 belongs to an insect specific clade of transporters that group with the sodium-dependent CCCs. Transcripts of aeCCC2 are highly expressed in epithelial tissues, especially the hindgut. Surprisingly, aeCCC2 induces sodium-dependent currents when expressed in *Xenopus* oocytes. We have further characterized the transport activity of aeCCC2 and its *Drosophila melanogaster* ortholog ncc83. In voltage clamp experiments, oocytes expressing aeCCC2 and ncc83 had greater sodium currents than water-injected controls. When membrane potential was allowed to fluctuate, it was strongly dependent on external sodium in oocytes expressing aeCCC2 and ncc83, but not in water-injected oocytes. Following a 10-minute hypotonic treatment, changes in membrane potential in response to sodium replacement were 20 ± 3 mV in ncc83 and 26 ± 4 mV in aeCCC2, approximately two-fold greater than before swelling. Changes in membrane potential or current due to sodium replacement occurred in the absence of external chloride and potassium. These results lead to the hypothesis that aeCCC2 and ncc83 are electrogenic sodium transporters that contribute to transepithelial salt transport in insects. Funding: American Physiological Society RCEA, NIH F33 GM131599, and Kenyon College.

44-6 GLYNN, KJ*; ZAHOR, DL; CHIPARUS, SL; CORNELIUS, JM; Eastern Michigan University, Oregon State University; *kglynn2@emich.edu*

Did the flint water crisis also harm wild birds? Examining blood lead of three urban birds in Flint, MI

Anthropogenic activities can emit metal pollutants, such as lead, into the environment and potentially elevate lead exposure in urban wildlife. Lead is toxic at relatively low concentrations and it has the potential to bioaccumulate and negatively impact the fitness of exposed organisms when introduced into an ecosystem. The route of exposure may vary across species depending on diet, excretion ability, and age. The Flint, MI water crisis introduced lead into some neighborhoods and likely into the soil via irrigation of lawns, threatening not only the health of humans, but also of urban wildlife. Avian species such as the American Robin, European Starling, and Gray Catbird commonly live within urban habitats and may be exposed differently to lead via diet preferences (i.e., initial exposure) or via physiological processes that impact the circulation or excretion of lead in the body. For example, nestlings and juveniles may be fed preferred food items that differ in quantity or type from adult diets, potentially influencing accumulation across age. Studies have also suggested that a potential pathway for excretion of lead in songbirds is through feather growth during molt or development and that lead can be stored and released as bone absorbs and releases calcium during growth processes. This study explores blood lead levels in several species of songbird in a city of known lead pollution to investigate accumulation across ages and whether or not blood lead changes across the molt. This preliminary study will provide insight into how lead moves through an ecosystem and how avian species of different age groups might be impacted by a sequestration of anthropogenic lead pollution.

72-4 GODOY, PL; Stony Brook University; *pedrolorenagodoy@gmail.com*

Cranial shape variation in Crocodylomorpha and the influence of ecological transitions during its evolutionary history

Today, the 27 modern crocodylian species display similar morphologies and occupy comparable ecological niches in their semi-aquatic environments. However, Crocodylomorpha, the group that includes includes the extinct relatives of living crocodylians, has an evolutionary history of more than 200 million years, which is reflected by a rich fossil record. Extinct crocodylomorphs exhibited much higher morphological disparity than extant ones, as well as remarkable ecological diversity, ranging from fully marine to completely terrestrial forms. In particular, cranial shape in crocodylomorphs seems to be integrated with ecological factors (such as feeding strategies), given the biomechanical implications of skull elongation and shortening. Nevertheless, the influence of ecological transitions on crocodylomorph cranial shape was never comprehensively investigated. I used geometric morphometric techniques and phylogenetic comparative methods to analyze cranial shape variation and disparity in crocodylomorphs and fully characterize its macroevolutionary patterns. I found a significant influence of ecological lifestyles (i.e. terrestrial, aquatic, and semi-aquatic) on cranial shape, as well as a strong size-shape relationship, indicating allometric shape changes (mainly in the snout region). Furthermore, I found that terrestrial species are more disparate in terms of cranial shape, particularly the mainly small-bodied notosuchians. I also found that aquatic and semi-aquatic forms are usually associated with regime shifts to more longirostrine crania and to larger body sizes. This suggests an intricate relationship between cranial shape, body size and ecology, and that clade-specific adaptations to different environmental conditions are determining large scale patterns of crocodylomorph cranial shape evolution.

11-6 GOEPPNER, SR*; LUTTBEG, B; Oklahoma State University; *scott.goeppner@okstate.edu*

Growth, lifespan, and reproductive investment of Physa snails exposed to predators

Past research has shown that *Physa snails* change their shell morphology, life history, and behavior based on the type of predators in their environment. The snails also exhibit transgenerational plasticity with individuals exposed to crayfish cues producing more crush resistant offspring. One explanation for this is that predator-exposed snails invest more in current offspring than control snails, at the expense of growth, life expectancy, and future reproduction. To test this hypothesis, we raised snails in one of four treatments: early-life predator exposure in which snails were exposed to crayfish cues for the first five weeks of life, late life predator exposure in which snails were exposed to crayfish cues for the second five weeks of life, continuous predator exposure in which snails were exposed to crayfish cues for both the first and second five weeks of life, or no predator exposure. We measured growth rate, age at first reproduction, egg production, and lifespan in the F1 snails. We then raised the F2 offspring of the F1 snails that produced at least 8 viable offspring at the end of the early and late life periods, and measured their size, shape, and crush resistance. In the F1 snails, we determined that early life predator exposure led to delayed reproduction, decreased egg production, and reduced lifespan, but had no effect on growth. Exposure to predator cue late in life had no effect on survival, growth, or egg production. Data analysis is ongoing for the effects of early and late life exposure on the size of eggs produced by F1 individuals and F2 phenotypes.

108-1 GOERIG, E*; DI SANTO, V; WAINWRIGHT, D K; CASTRO-SANTOS, T; AKANYETI, O; LIAO, J; LAUDER, G; Harvard University, Stockholm University, Yale University, USGS Leetown Science Center, Aberystwyth University, University of Florida; *goerig.elsa@gmail.com*

Comparative Undulatory Kinematics in Swimming Fishes: Rethinking Swimming Modes

Biologists studying fish locomotion have traditionally classified undulatory fish kinematics into categories named after exemplar species. Fishes that are thought to swim with relatively short body wavelengths that incorporate the entire body are referred to as "anguilliform" (after the eel *Anguilla*), while those swimming with progressively longer wavelengths that undulate a smaller portion of the body are termed "subcarangiform", "carangiform", and "thunniform" (after tuna, *Thunnus*). Under this scheme, lateral amplitude oscillations of the anterior body decrease progressively from eels to tuna. In order to compare undulatory swimming kinematics in fishes, we have assembled a quantitative data set of body midline kinematics across 45 species including eels, mackerel, trout, and tuna. High-speed video data were obtained from both laboratory flow tanks and a field-based high-speed flow tank where fish can exhibit volitional high-speed locomotion. We combine metrics derived from midline kinematics with measurements of body depth and width for each species. A multidimensional analysis shows that morphology captures a significant proportion of the variance in the data, while there is considerable similarity in midline kinematics among species as diverse as eels and tuna. These results question the validity of the longstanding categories used to describe the body kinematics of swimming fishes, and instead suggest that these "swimming" modes may simply represent morphological categories. In the future our multi-species kinematics database will be available for use in comparative studies of fish locomotion and for programming fish robotic systems.

63-4 GOFORTH, KM*; LOHMANN, CMF; LOHMANN, KJ; University of North Carolina at Chapel Hill; *kaylago@live.unc.edu*

The Role of Magnetic Field Detection in Foraging Site Fidelity of Sea Turtles

Foraging site fidelity describes a pattern of behavior in which animals return to the same foraging area repeatedly, in some cases after migrating to distant sites. Juvenile sea turtles of several species exhibit this behavior, with turtles reliably returning to specific foraging grounds following seasonal migrations and experimental displacements. Turtles are known to have a magnetic map sense that exploits variation in Earth's magnetic field to identify and travel to distant sites. Because of this variation, different geographic locations have slightly different magnetic fields, thus, most foraging areas have a unique "magnetic signature". In principle, turtles might learn to navigate to a specific foraging area by learning the magnetic signature of that site. To investigate this possibility, we studied whether turtles are capable of learning to associate a magnetic signature with food. Captive loggerhead turtles (*Caretta caretta*) approximately three months of age, were assigned to one of two experimental groups and conditioned to a unique magnetic field. Each group was exposed to two different magnetic signatures, on a daily alternating schedule, over the course of two months. Turtles spent equivalent amounts of time in the two magnetic signatures, but only received food in one of them. In post-conditioning trials conducted in the absence of food, turtles exhibited higher levels of food-seeking behavior when exposed to the magnetic field in which they had previously been fed, but not when exposed to the other magnetic field. These results provide the first direct evidence that sea turtles can learn to associate a magnetic field with food, a process that may underlie the development of foraging site fidelity.

11-1 GOLDBERG, DL*; BASSINGTHWAITE, TA; BEILKE, S; WARD, MP; CAPPARELLA, AP; Illinois State University, Audubon Great Lakes, Chicago, University of Illinois at Urbana-Champaign; *dlgoldb@ilstu.edu*

Calling Owl: Rails Do Not Reduce Vocal Activity Rates in Response to Predation Risk

Animal communication carries the risk of signal exploitation by predators, and thus many species will adjust their behavior to produce signals that range from more discreet messages to conspecifics, to conspicuous anti-predator cues. Although rails (Family Rallidae) are known to use the visual display of tail-flicking as a warning of vigilance towards predators, how these birds will alter their frequent and diverse vocal behavior based on perceived predation risk remains little studied. The calls of owls, which consume a variety of rallid species and can home in on acoustic cues of their prey, have been found to reduce singing in numerous other birds. We applied remotely-activated broadcasts and Autonomous Recording Units to study whether rails in the wetlands of the Lake Calumet region near Chicago would decrease vocal activity rate (VAR) following the broadcast of a known rallid predator, the Great Horned Owl (*Bubo virginianus*). In our comparison of different wetland sites that varied in the historical presence of owls, neither Soras (*Porzana carolina*) nor Virginia Rails (*Rallus limicola*), nor both species combined, showed a significant reduction in VAR in experimental relative to control trials. As the rails at Lake Calumet showed a general trend of higher VAR with the onset of the breeding season, our results indicate that these rallid species may signal alarm despite owl predation risk, or that they employ alternative, currently unknown behavioral strategies to mitigate this risk.

96-5 GOLOS, MR*; BAUER, U; University of Bristol; *michal.golos@bristol.ac.uk*

Wettability of Pitcher Plant Trapping Surfaces

Carnivorous plants have evolved a myriad of highly elaborate structures in order to attract, trap, and retain their prey. Notable among these are the main trapping surfaces of tropical pitcher plants (*Nepenthes* and *Heliamphora*), which exhibit highly ordered, hierarchical microstructures that confer a suite of interesting properties, including (super)hydrophilicity, water film stabilisation, and directional water spreading. These surfaces are unusual in that they are highly wettable yet lack the discontinuities in the waxy cuticle that characterise most hydrophilic plant surfaces. We explored how a glabrous, non-glandular, non-porous, primary plant surface can nonetheless exhibit these wetting properties, investigating the influence of both topography and surface chemistry in order to disentangle their relative contributions. Understanding how the form and chemistry of these structures renders them well-wettable and capable of rapid directional water transport has the potential to open new avenues for research into bioinspired technologies.

32-7 GOODCHILD, CG*; DURANT, SE; Oklahoma State University, University of Arkansas; *christopher.goodchild@okstate.edu*

Is a novel marker of oxidative damage linked to aerobic scope and flying performance in birds exposed to crude oil?

Birds externally exposed to crude oil have impaired flying performance due to crude oil damaging the microstructure of feathers. However, crude oil ingestion can also damage red blood cells (RBCs), which may reduce oxygen delivery to muscles and further limit flying performance. Although RBC damage has been previously described in birds exposed to crude oil, the effects of crude oil ingestion across levels of biological organization (e.g., RBC damage, metabolic scope for activity, and flying performance) remains unclear. In this study, we orally dosed zebra finches (Taeniopygia guttata) with 2 or 6 ml/kg of artificially weathered MC252 crude oil for 28 days and measured RBC integrity using traditional and novel endpoints, basal and maximal metabolic rates using a 'hop-flutter' chamber, and vertical flight speed and takeoff acceleration using a high-speed camera. Crude oil ingestion caused a decrease in packed cell volume (PCV) and an increase in reticulocytes, indicating regenerative anemia. Furthermore, we also detected an increase in fluorescent heme-degradation products (HDPs), a novel tool for measuring oxidative damage. Crude oil ingestion caused a reduction in resting metabolic rate, maximum metabolic rate, and aerobic scope. Interestingly, we found that birds exposed to crude oil increased vertical flight speed. Crude oil ingestion also caused a decrease in fat score, which may explain why oiled birds increased flight speed. Our results suggest that RBC damage in birds exposed to crude oil has metabolic consequences, but the metabolic effects do not impair short-range, burst flight.

105-8 GOODMAN, CM*; BUCKMAN, KN; HILL, JE; TUCKETT, QM; ROMAGOSA, CM; University of Florida; *colin.goodman@ufl.edu*

Dispersal, performance, and Morphometry of a Novel Invader (Xenopus tropicalis) in Central Florida: Evidence of Spatial Sorting?

A primary determinant of long-term invasion success is a species' ability to colonize novel environs. Colonization success is linked to the dispersal rates of individuals within the invading population. The traits that confer increased dispersal rates are often heritable and are, therefore, open to selection pressure. This pressure can lead to spatial sorting, whereby individuals that are more effective dispersers naturally align themselves along the invasion front, hastening the spread of the invasion. Using the extant invasion of *Xenopus tropicalis* in Florida as a system, we examined individual, sex, and site-level differences in both morphometry and performance as they relate to dispersal distance and success. We predicted that individuals that disperse should have longer hind-limbs and better stamina, relative to individuals that do not disperse. Additionally, we predicted that individuals with better exertion capacity would be more likely to disperse longer distances. We found significant differences in performance, with individuals that dispersed performing for longer intervals before reaching exhaustion than individuals that did not disperse. Additionally, we found that both morphometry and performance predicted dispersal distance, with dispersal distance increasing with both hind limb length and maximal exertion capacity. These results suggest that dispersal success is nonrandom with respect to morphometric and performance traits, and may indicate the real-time progression of spatial sorting.

15-4 GORMAN, CE*; BOND, L; VAN KLEUNEN, M; DORKEN, M; STIFT, M; University of Konstanz, BW, Germany , Trent University, Peterborough, ON, Canada, University of Konstanz, BW, Germany and Zhejiang Provincial Key Laboratory of Plant Evolutionary Ecology and Conservation, Taizhou University, China; *cgorman22@gmail.com*

Phenological and pollinator-mediated isolation among selfing and outcrossing Arabidopsis lyrata populations

Mating system transitions from outcrossing to selfing have been a frequent evolutionary shift in plants and clearly play a role in species divergence. However, many questions remain about the initial mechanistic basis of reproductive isolation during the evolution of selfing. For instance, how important are prezygotic pre-pollination mechanisms (e.g. changes in phenology and pollinator visitation) in maintaining reproductive isolation between newly arisen selfing populations and their outcrossing ancestors? To test whether changes in phenology and pollinator visitation isolate selfing populations of *Arabidopsis lyrata* from conspecific outcrossing populations, we conducted a common garden experiment with plants from selfing and outcrossing populations as well as their F1 hybrids. Specifically, we asked whether there was reproductive isolation between outcrossing and selfing plants and their F1 hybrids through differences in 1) the timing or intensity of flowering; and/or 2) pollinator visitation. We found that phenology largely overlapped between plants from outcrossing and selfing populations. There were also no differences in pollinator preference related to mating system. Additionally, pollinators preferred to visit flowers on the same plant rather than exploring nearby plants, regardless of whether they were of an alternative mating system type or F1 hybrids, creating a large opportunity for self-fertilization. Together, this suggests that prezygotic pre-pollination mechanisms do not strongly reproductively isolate plants from selfing and outcrossing populations of *A. lyrata*.

69-3 GORMALLY, BMG*; ESTRADA, RS; MCVEY, M; ROMERO, LM; Tufts University; *brenna.gormally@gmail.com*

Expanding the acute stress phenotype: DNA damage rapidly increases in house sparrows

Corticosterone (Cort) is the metric of choice in stress physiology studies. Despite its popularity, this hormone often does not accurately reflect how an animal copes with a stressor, likely due to its complex actions. Furthermore, changes in Cort are rarely consistent across contexts, life-history stages, and species. By focusing solely on this hormone, we reach an incomplete picture of how animals cope with unpredictable stimuli; a separate, independent measure is thus needed. In this study, we tested the hypothesis that acute increases in DNA damage could serve as an adjunct to Cort when assessing stressor exposure. Previous studies have found that DNA damage increases in response to stress-related hormones in vitro, prompting further exploration in wild animal systems. We exposed house sparrows (*Passer domesticus*) to a short (30 or 120-minute) restraint stressor and took blood samples at 0, 30, 60, and 120 minutes to measure Cort, DNA damage, and uric acid. DNA damage and Cort increased while uric acid decreased. DNA damage can thus reflect acute stressor exposure. We also tested the impacts of freezing on DNA damage in the hopes that this method will become more applicable in field-based studies. Leaving red blood cells on ice for up to 24 hours resulted in statistically significant, but likely not important, increases in DNA damage. Freezing blood samples for up to 4 weeks substantially increased DNA damage. These findings emphasize the importance of assaying samples together whenever possible. Overall, these results indicate that DNA damage can reflect whether and how an animal is coping with a stressor.

85-6 GOULD, FDH*; LAMMERS, A; MAYERL, CJ; GERMAN, RZ; Rowan University School of Osteopathic Medicine, Stratford NJ, Cleveland State University, Cleveland OH, Northeast Ohio Medical University, Rootstown, OH, Northeast Ohio Medical University, Rootstown, OH; *gouldf@rowan.edu*

Differential Effect of Superior and Recurrent Laryngeal Nerve Lesion on Kinematics and Performance in Mammalian Swallowing

Mammalian swallowing is complex at anatomical, functional, and neurological levels. The complexity of swallowing physiology means that multiple points may lead to similar failure in performance, specifically failure to protect the airway. The superior laryngeal nerve (SLN) and the recurrent laryngeal nerve (RLN) are branches of the Vagus that innervate different structures involved in swallowing. Although they have distinct sensory and motor fields, lesion of either nerve leads to a decrease in airway protection. We tested the hypothesis that despite similar outcomes in terms of airway protection, SLN and RLN lesion would impact oropharyngeal kinematics differently. To test the effect of lesion of either nerve on kinematics, we recorded 11 infant pigs swallowing milk using high speed videofluoroscopy before and after either unilateral SLN or RLN lesion. Because of the repeated measures design each animal acted as its own control. We measured oropharyngeal kinematics from the videofluoroscopic recordings. Posterior tongue kinematics during swallowing respond differently to RLN lesion and SLN lesion ($p=0.007$). Furthermore the relationship between tongue kinematics and airway protection outcome differs in SLN and RLN lesion ($p=0.045$). Thus, although SLN and RLN lesion lead to the same performance failure, the effect on tongue kinematics and their relationship to airway protection failure are different. The complex connections that exist in mammalian feeding systems result in a many-to-one relationship between function and performance, and has significant implications for understanding how complex systems are functionally integrated in ontogeny and evolution.

129-6 GOULD, A*; FRITTS-PENNIMAN, A; California Academy of Sciences; *agould@calacademy.org*
Shedding light on specificity: the phylogeography of a bioluminescent symbiosis
All organisms depend on symbiotic interactions with bacteria for their success, yet little is known of the evolutionary processes that shape the specificity of these associations. Coral reef fish in the genus *Siphamia* form symbiotic associations with luminous bacteria, which they provision in a gut-associated light organ. There are 25 described *Siphamia* species that are distributed throughout the Indo-Pacific, however, the light organ symbionts of only a single host species, *S. tubifer*, from a small region in the Okinawan Islands, Japan have been described to date. Using Siphamia specimens archived in natural history collections and applying whole genome shotgun sequencing methods, the luminous symbionts of 15 host species were identified. Additionally, the light organ symbionts of *S. tubifer* specimens from locations representing their broad biogeographic distribution, ranging from eastern Africa to French Polynesia were described. Using targeted sequence capture methods, the phylogenetic relationships across the host genus were also inferred and compared to that of their luminous symbionts to test for evidence of co-divergence of host and symbiont. Results indicate that the bioluminescent symbiosis is highly conserved across the host genus; the light organ symbionts of all Siphamia species examined were identified as Clade II of *Photobacterium mandapamensis*, the luminous symbiont of *S. tubifer* that was previously identified. Furthermore, the association between *S. tubifer* and *P. mandapamensis* is highly conserved throughout the host's broad Indo-Pacific distribution and through time. This high degree of specificity observed for this bioluminescent symbiosis suggests that the association could be genetically constrained at the genus level and presents the opportunity to investigate the genetic mechanisms regulating the specificity of host-microbe associations.

125-5 GRACE, JK*; ANGELIER, F; Texas A&M University, Centre d'Etudes Biologiques de Chize, CNRS; *jkgrace@tamu.edu*
Post-natal Glucocorticoids Negatively Affect Adult Anti-predator Behavior in House Sparrows
Short-term behavioral effects of early-life stressor experience and/or elevated glucocorticoids are widely documented across vertebrates. However, the persistence and severity of these effects are largely unknown, especially through the adult stage and in wild species. We investigated long-term effects of experimental post-natal increases in circulating corticosterone on antipredator behavior in house sparrows (*Passer domesticus*). We manipulated circulating corticosterone concentration in wild, free-living nestlings, transferred fledglings to captivity, and tested juveniles and adults for two measures of antipredator behavior: evasiveness during a direct human encounter, and propensity to escape from a risky environment. We found no effect of treatment on escape behavior, but a delayed effect on evasive behavior: treatment lowered evasive behavior in adults but not juveniles, and this effect was moderated by current body condition. These results highlight the importance of state-behavior interactions and life stage in assessing long-term effects of early-life stress, and provide rare evidence for delayed effects of early-life stress to adulthood.

123-8 GRAHAM, Z/G*; GARDE, E; HEIDE-JøRGENSEN, M/P; PALAORO, A/V; Arizona State University, Greenland Institute of Natural Resources, Universidade Federal de São Paulo; *zgraham1@asu.edu*
What is the Function of the Narwhal's Tusk? Insights from Morphology
The narwhal tusk is undoubtedly one of the most charismatic structures in all of biology, protruding from the head of male narwhals and reaching lengths of up to 3-m. Recent evidence has arisen that proposes that narwhals may use their tusk to stun prey or sense changes in water quality. By contrast, because all males and only a small percentage of females develop a tusk; this suggests that the tusk may function as a weapon during male-male aggression or as a signal during female-mate choice. Hence, clear inconsistencies arise when attempting to distinguish between these functions. Because direct observations of narwhal behavior are nearly impossible, we studied morphological scaling and variation in adult narwhals. With our analyses, we demonstrate that the size of the narwhal tusk scales steeply with body size. Additionally, substantial variation in tusk size for a given body size supports the hypothesis that the tusk is sexually selected. Overall, we propose that the narwhal tusk is an exaggerated weapon used during male-male competition but may also serve additional functions.

90-2 GRANATOSKY, MC*; LAURENCE-CHASEN, JD; GARTNER, SM; WHITLOW, KR; WESTNEAT, MW; NYAKATURA, JA; New York Institute of Technology, University of Chicago, Humboldt-Universität zu Berlin; *Michael.Granatosky@nyit.edu*
An XROMM and kinetic analysis of underwater walking in the West African lungfish (Protopterus annectens) with implications for the role of quadrupedal gaits during the fin-to-limb transition
The integration of experimental data and modelling techniques have generated novel hypotheses about the fin-to-limb transition. One such hypothesis suggests that early tetrapods were incapable of salamander-like walking gaits. However, some dipnoans are well-known for their propensity for underwater walking. As such, it is possible that the neuromuscular substrates for quadrupedal gaits did not evolve during the invasion onto land, but instead for movement on benthic substrates. If true, living salamanders may be too anatomically derived to be particularly informative about the locomotor patterns of early tetrapodomorphs. In this study, we collect limb-loading data and three-dimensional femoral kinematics using X-ray Reconstruction of Moving Morphology from the West African lungfish (*Protopterus annectens*) during underwater walking. These data are compared to patterns of terrestrial locomotion in three species of salamander. Limb-loading in lungfish is dramatically lower than predicted based on their body mass, presumably due to the lungs providing additional buoyancy. However, when scaled to the underwater mass of the animal, limb-loading patterns and magnitudes are comparable to salamanders. Movements and overall excursion of femoral protraction/retraction and abduction/adduction are similar between walking lungfish and salamanders. However, long-axis rotation of the femur is substantially lower during quadrupedal walking in lungfish. These findings suggest that despite limited long-axis rotation of the femur, as has been posited for some stem tetrapods, quadrupedal gaits and tetrapod-like limb loading patterns can be achieved.

28-2 GRAND PRE, CA*; HEDRICK, BP; SCHACHNER, ER; Louisiana State University Health Science Center, New Orleans; *cgran9@lsuhsc.edu*

Movement and Function of the Hepatic-Piston Pulmonary Apparatus During Various Modes of Respiration in the American Alligator (Alligator mississippiensis)

Investigating the evolution of the respiratory system of crocodilians requires a thorough understanding of functional pulmonary anatomy and the associated osteological correlates in extant crocodilians. Previous work suggests that the hepatic-piston pump in extant crocodilians is correlated with a smooth thoracodorsal ceiling, which allows for the free movement and displacement of the lung and pleura during hepatically-driven ventilation, which has been suggested to only engage after vigorous exercise. However, this free movement and displacement of the pleura has neither been confirmed nor measured in living crocodilians. We present our initial results of ultrasound data of the pleura of two juvenile specimens of *Alligator mississippiensis*. Ultrasound was used to record the hepatic-piston driven ventilation and pleural displacement under three different conditions: 1) the alligators were measured in a calm, natural state, with typical shallow breathing; 2) the alligators inspired a 5% CO_2 fixed N_2 gas to invoke deep breathing; and, 3) the alligators were measured after exercise (breathing freely without CO_2 gas). These preliminary data demonstrate that hepatic-piston pump ventilation and pleural displacement occurred craniocaudally under all three conditions. The amount of pleural and hepatic displacement increased dramatically after CO_2/N_2 delivery. Our data demonstrate that the hepatic-piston ventilation system is functional both during shallow breathing and induced large breaths, and confirms that the smooth thoracodorsal ceiling allows for the free displacement of pleura and lung tissue.

113-3 GRANGER, J*; WALKOWICZ, L; FITAK, R; JOHNSEN, S; Duke University, Adler Planetarium; *jngranger@email.wm.edu*

Gray Whales Strand More Often on Days With Increased Levels of Atmospheric Radio Frequency Noise

Relatively little is known about how large marine mammals, such as whales, accomplish their impressive long-distance migrations. An underexplored sensory modality is magnetoreception: the ability to derive positional and directional information from the earth's magnetic field. Baleen whales are a candidate group for investigating magnetoreception in mammals due to their long migrations and the unique navigational challenges they face in the featureless open ocean. In this environment, it could be advantageous to derive navigational cues from the geomagnetic field because it is relatively constant and ubiquitous. While it is difficult to perform behavioral experiments on whales, it may be possible to use live stranding data (strandings in which the whale may have made a navigational error, rather than those in which a whale died at sea and washed ashore) as a tool for investigating their navigational senses. We used gray whale (*Eschrichtius robustus*) stranding data from the US west coast (n=186). We found that gray whales strand more often on days with high levels of solar radio flux (RF, $p<0.0001$) than on random calendar days. RF is strongly correlated with solar storms – sudden releases of high-energy particles from the sun that interact with parts of the earth's magnetosphere. One hypothesized mechanism for magnetoreception, the radical-pair mechanism, predicts that magnetoreception can be disrupted by radio-frequency radiation, and RF noise has been shown to disrupt magnetic orientation in certain species. These results indicate a magnetic sense in whales, which may be mediated by a radical-pair mechanism.

42-5 GRAY, JA*; SHERRATT, E; HUTCHINSON, MN; JONES, MEH; Oklahoma State University Center for Health Sciences, University of Adelaide, South Australian Museum, University College London; *grayjaimi@gmail.com*

Dragons of the trees, the rocks, and the ground: the evolution of cranial shape in a continental-scale evolutionary radiation of lizards (Lepidosauria: Agamidae)

Morphological disparity can be generated during adaptive radiations in response to factors such as new resources, freedom from competition, and an absence of predators and pathogens. The oldest ancestor of the extant Australian radiation of agamid lizards (Amphibolurinae) arrived in Australia from Southeast Asia approximately 30 million years ago. Since then, Australian agamids have become a species-rich and ecologically diverse clade. Today, they are comprised of around 120 species distributed among every Australian habitat, and are particularly successful in arid environments. We have relatively sound knowledge of their taxonomic diversity and phylogenetic relationships, but their morphological diversity remains largely unexplored. Despite being such a taxonomically and ecologically diverse clade, their adaptive character has not been explicitly tested. Here, we use three-dimensional geometric morphometrics to characterise skull shape in Australian agamids and their Asian agamid relatives (Draconinae), and investigate the association between skull shape and ecological life habit. We find that in addition to phylogenetic affinity and evolutionary allometry, ecological factors play a major role in skull shape evolution of this clade, confirming their adaptive character. Through our evaluation of the cranial morphospace we find common themes of ecomorphology, where tree-dwelling species have long skulls and snouts, terrestrial species have short, blunt skulls, and saxicolous species have dorsoventrally flat skulls. These characteristics likely result from trade-offs to optimise functional capabilities, which often play a role in the evolution of skull shape.

123-6 GREEN, TL*; GIGNAC, PM; Oklahoma State University Center for Health Sciences, Tulsa; *todd.green@okstate.edu*

Cassowary Casques are Lightning Rods for Speculation: Anatomical Development and Phenotypic Variation Clarifies Potential Biological Roles

The cranial casques (i.e., bony and keratinous dorsal skull projections) of extant cassowaries (*Casuarius*) have been of interest to researchers since the 17th century due to their conspicuousness. Casque biological roles, however, remain poorly understood, limiting our understanding of the life history of these unique birds as well as the selective conditions under which cranial elaborations appear in archosaurs. A strict focus on adult ornaments has left surprisingly few links to ontogeny, life history, and function. Moreover, the handful of osteological interpretations of casques are contradictory, illustrating the difficulty by which full documentation of this anatomy has proceeded. Four primary hypotheses for casque function have been proposed: (1) ramming, (2) vocalization, (3) thermoregulation, and (4) display. To address these roles, we undertook µCT analyses of cranial anatomy in a developmental series of southern cassowaries (*C. casuarius*), capturing details of external and internal structures as well as timings of sutural fusions and inflations of casque elements. We compared the developmental timing of casques to physical, behavioral, and reproductive maturity to determine the plausibility of each function. Our sample (n = 110) indicates the majority of casque growth occurs prior to sexual maturity; however, casque morphology continues to change substantially throughout adulthood. In *C. casuarius* casque deviation from midline is common, and such asymmetries appear to be primarily dextral. Form does not support functions for physical ramming or vocalization. Thermoregulation and display are not refuted by developmental anatomy and adult phenotype, necessitating more focused study.

125-7 GREVILLE, LJ*; POLLOCK, T; DECATANZARO, D; FAURE, PA; McMaster University, Hamilton, ON; *grevillj@mcmaster.ca*

Seasonal Variation in Estradiol Transfer Among Male and Female Big Brown Bats

Current research suggests that unconjugated steroids excreted in the urine of male mice alter the reproductive behaviour and physiology of female conspecifics. These observations support the notion that steroids can act as pheromones in mammals. Using tritium (^{3}H)-labelled estradiol (E_2) as a radioactive tracer, we have shown that female big brown bats (*Eptesicus fuscus*) readily absorb exogenous ^{3}H-E_2 applied via cutaneous and intranasal exposure, with radioactivity measured throughout neural, peripheral, and reproductive tissues 1 hour after exposure. Additional experiments with ^{3}H-E_2 have shown the reliable transfer of estradiol from male *E. fuscus* to cohabitating female conspecifics during the Autumn mating season. Here we explore seasonal variation in estradiol transfer between male and female *E. fuscus* at three relevant time points: Autumn (mating season), Spring (female ovulation, ovum fertilization, and implantation), and Summer (maternity colony formation, parturition, and maternal care). We found substantial seasonal variation in the amount of ^{3}H-E_2 transferred from males to a variety of female tissues, including the frontal cortex, heart, liver, uterus, and blood serum, with a number of other tissues approaching statistically significant differences among seasons. We present data demonstrating the presence of unconjugated and bioactive estradiol in male urine across the mating cycle, with the peak concentration occurring during reproductively relevant times. We concluded that estradiol is a likely vector for steroid transfer between individuals. Seasonal variation in estradiol transfer could influence sexual behaviour and reproductive physiology of female bats during critical reproductive periods, as transferred steroids were found in both neural and reproductive tissues.

23-6 GRIFFITHS, JS*; JOHNSON, KM; KELLY, MW; Louisiana State University; *jgrif61@lsu.edu*

Evolutionary Change in the Oyster, Crassostrea virginica, Following an Experimental Low Salinity Event

The eastern oyster, *Crassostrea virginica*, is known for its tolerance to a wide range of salinities, but evidence suggests that some populations may be adapted to their local salinity regime. Distance from the Mississippi River is correlated with increased salinities and oysters are expected to have a decreased tolerance to low salinity as distance from the Mississippi River increases. Larval survival is strongly influenced by the salinity conditions of the parental stock, suggesting that larvae from their 'home' or 'parental' salinity regime have higher survival than in a 'foreign' environment with a different salinity. Oysters have high levels of gene flow which could impede local adaptation, but strong selective gradients may cause differential survival of native and foreign oyster recruits, leading to population structure and adaptation to local salinity regimes. To test for evidence of local adaptation by differential larval survival we imposed a low salinity (7 ppt) selection event on oyster larvae from Louisiana (low salinity environment) and Texas (high salinity environment) populations. A subsample of larvae was collected before and after a 12-hour low-salinity exposure for genetic analyses. "Live" oysters were collected from the top 900mL of the jar and "dead" oysters were collected from the bottom 100mL of the jar. We observed 99% mortality in larvae from the high salinity Texas population and only 70% mortality in larvae from the low salinity Louisiana population, suggesting population-specific survival rates. Using exome capture, we sequenced 150 salinity-associated genes and observed allele frequency shifts in survivors before and after low salinity exposure. These genes are potential candidates under low salinity selection that maintain population structure in *C. virginica* in the Gulf of Mexico.

43-3 GRIMES, CJ*; PAIVA, PC; PETERSEN, L; SCHULZE, A; Texas A&M University at Galveston, Universidade Federal do Rio de Janeiro; *cg1478@tamu.edu*

How fireworms, Hermodice carunculata, react to hypoxia: morphological, physiological and gene expression responses

The bearded fireworm, *Hermodice carunculata*, is a resilient amphinomid annelid, found throughout the Atlantic Ocean under a wide range of environmental conditions. Due to the species' ease of capture, culture, widespread, and abundant nature, it is very suitable for experimental studies of environmental tolerance. Here, we have subjected *H. carunculata* to intermittent (< 18 hours) and chronic (> 18 hours) hypoxia to investigate the species' molecular and morphological responses to such stressful situations. For chronic hypoxia, five bearded fireworms were exposed to one of three levels of dissolved oxygen (DO) in 40-liter tanks for seven days: 2.5 (± 0.25) mg/l, 4.5 (± 0.25) mg/1, and 7 (± 0.25) mg/1 (normal DO). To investigate intermittent hypoxia responses, 16 worms were subjected to intermittent hypoxia (6 hours of hypoxia and 18 hours of normoxia) for 2 days and sampled for tissues at 6, 18, 24, and 42 hours. The morphological comparisons before and after hypoxia exposure show an increase in the surface area of branchial tufts. Differential gene expression analyses suggest up-regulation of stress response genes, metabolic depression, and an increase in efficiency of oxygen transport molecules under hypoxic conditions. This study allows us to infer the threshold DO level for hypoxic response in this abundant coral reef inhabitant, predict downstream responses to this stressful condition, and potentially predict the historical DO levels for an area where the worms are found.

11-4 GRIPSHOVER, ND*; JAYNE, BC; University of Cincinnati; *gripshnd@mail.uc.edu*

Feeding of Crayfish Snakes: A Model System for Testing the Roles of Predator Anatomy and Behavior on Foraging Ecology

Snakes are a classic example of a gape-limited predator, but ironically gape has been quantified directly in fewer than 10 of more than 3,500 extant species. Besides an anatomy specialized for large gape, snakes seem likely to require additional specializations for unusual types prey, such as crustaceans. In this study, we quantified maximum gape and its scaling relationships for two natricine snake species (*Regina septemvittata*, *Liodytes alleni*) that primarily prey upon freshly molted (soft) or hard-shell crayfish, respectively. We also quantified the relative area (RelA) of prey consumed in the field and in the lab as a percentage of the maximal cross-sectional area of snake gape. For snakes with equal snout-vent length, the maximal gape of *L. alleni* (N=26) was significantly larger than that of *R. septemvittata* (N=21). In the field, *R. septemvittata* (N=148) consumed large prey (RelA>50%) more often than *L. alleni* (N=17) (38% vs. 22% of stomach contents). For equal RelA during laboratory trials, *L. alleni* consumed soft-shell prey significantly faster than hard-shelled prey. However, presumably as a result of its coiling behavior, *L. alleni* consumed soft-shell crayfish significantly faster than *R. septemvittata*. In laboratory trials of *L. alleni*, when prey exceeded 50% RelA the success rates of attacks were 11% and 48% for hard-shelled (N=19) and soft-shelled (N=42) crayfish, respectively. Similar to the two natricine study species, the Southeast Asian snake that eats hard-shell crabs has larger gape but eats prey with smaller relative size than its sister species that eats only soft-shell crabs. Hence, the primary constraints of snakes for the maximal prey size when eating hard-shell and soft-shell crustaceans are probably the ability to capture prey and maximal gape, respectively.

45-3 GROBER, M S*; PRADHAN, D S; Georgia State University, Idaho State University; *mgrober@gsu.edu*
Rosemary Knapp: scientist, colleague, mentor, friend
I will spend my 15 minutes talking about how Rosemary Knapp helped Devaleena Pradhan (my graduate student) to better develop a great piece of science that was a significant part of her dissertation. She essentially co-mentored Devaleena by giving excellent feedback at her SICB poster AND, after we improved the study as a result of her feedback, via her excellent service as an editor at Proceedings of the Royal Society, London. The story is a testament to what a great scientist, mentor and colleague Rosemary was and also what a great friend she was to me. While the story will be about Rosemary, some neat data about how brain derived androgens regulate paternal care in the Bluebanded Goby will make an appearance, since this is the study that Devaleena was presenting at SICB when Rosemary dropped by and made everything better.

27-7 GUERNSEY, MW*; VAN KRUISTUM, H; REZNICK, DN; POLLUX, BJA; BAKER, JC; Stanford University School of Medicine, Wageningen University, University of California, Riverside; *michael.w.guernsey@gmail.com*
Poeciliopsis maternal follicle transcriptomes reveal importance of placenta and secretory genes in the emergence of live-birth
Placentation evolved many times independently in vertebrates, and while the core functions of all placentas are similar we know less about how this similarity extends to the molecular level. Here we study *Poeciliopsis*, a unique genus of live-bearing fish that have evolved placental structures at least three times independently. The maternal follicle is a key component of these structures; it envelops yolk rich eggs and is morphologically simple in non-placental species, but has elaborate villous structures in placental species. Through sequencing the follicle transcriptome of a placental, *P. retropinna*, and non-placental, *P. turrubarensis*, species we found genes known to be critical for placenta function expressed in both species despite their difference in complexity. Additionally, when we compare the transcriptome of different river populations of *P. retropinna*, known to vary in maternal provisioning, we find differential expression of secretory genes expressed specifically in the top layer of villi cells in the maternal follicle. This provides some of the first evidence that the placental structures of *Poeciliopsis* function using a secretory mechanism rather than direct exchange between maternal-fetal circulation. Finally, when we look at the expression of placenta proteins at the maternal-fetal interface of a larger sampling of *Poeciliopsis* species we find expression of key maternal and fetal placenta proteins in their cognate tissue types of all species, but follicle expression of Prolactin is restricted to only placental species. Taken together, we suggest that all *Poeciliopsis* follicles are poised for placenta function, but require expression of key genes to form secretory villi.

54-7 GUERRA CANEDO, VI*; HART, MW; KOEPFLI, KP; Simon Fraser University, Burnaby, BC and Smithsonian Conservation Biology Institute, Washington, DC, Simon Fraser University, Burnaby, BC, Smithsonian Conservation Biology Institute, Washington, DC; *vguerracanedo@gmail.com*
Evidence of positive selection in genes known to regulate fertilization in Mustelids
Gamete-recognition proteins (GRG), expressed on the surface of gametes, mitigate the initiation of sperm hyperactivation, acrosome reaction, gamete binding and fusion. Few genetic changes in these proteins can lead to reproductive incompatibility. GRG are poorly described in mustelids and other mammals. This is in part due to duplication events, diversifying selection, loss of function, and convergence. Conservation breeding efforts of endangered species are encountering an increased number of fertilization problems linked to gamete health. For example, since the onset of the captive breeding program, the percentage of structurally-normal spermatozoa in the black-footed ferret has decreased from 50% to 20%, coincident with a decline in testes size. These features are indicative of inbreeding depression. To better understand fertilization in mustelids, we used whole genome data comparison to find and characterize genes linked to fertilization. In particular, we focused on finding orthologous GRG in mustelids and related taxa of the Carnivora. We characterized eight potential GRG and tested these for signatures of positive selection within a phylogenetic and machine learning framework using the software toolkit HyPhy. We identified regions of these genes under positive selection in mustelids, which have also been previously identified to be under selection in mice and humans. Our findings can help inform functional analyses to confirm the patterns of expression and function of these orthologous GRG in mustelids and other carnivores. Furthermore, these genes can be used in combination with additional fertilization genes to identify healthy gametes for ex situ and in situ population breeding efforts of endangered species.

8-3 GUIDRY, ME*; REIGEL, AM; KELLY, MW; Louisiana State University ; *mguid73@lsu.edu*
Variation in the Microbiome of the Eastern Oyster: Environmental Influences and Effects on Oyster Health
Crassostrea virginica (eastern oysters) are ecologically and economically valuable organisms in coastal Louisiana. Understanding the nuanced relationships between *C. virginica* hosts and associated microbiota could be the key to maintaining healthy populations along a dynamic coastline. This study utilizes the natural salinity gradient along the Louisiana Gulf coast to analyze the effect of variable environmental conditions and disease on the *C. virginica* microbiota. Oysters were collected from two parent sites in Louisiana: Lake Calcasieu (19.4 ± 2.5ppt) and Vermillion Bay (3.9 ± 1.9ppt). Oyster stocks were spawned at the Louisiana Sea Grant Grand Isle Hatchery, and offspring were outplanted to Grand Isle (19.9 ± 4.2ppt) and LUMCON (8.0 ± 3.5ppt) for 14 months. Oyster gill tissue and pallial fluid samples were collected from both sites in July and October of 2018. Microbial DNA was extracted from gill tissue and pallial fluid samples and sequenced for 16S rRNA (V4 region) using Illumina HiSeq for 2x250bp reads. The progression of Dermo infection, caused by parasitic protozoan *Perkinsus marinus*, was measured and recorded for all individuals. By comparing microbiomes from gill tissue and pallial fluid and different environmental conditions, we were able to gain an initial understanding of the diversity of the *C. virginica* microbiota. Data suggest signature microbial communities for gill tissue and pallial fluid, as well as outplant-site specific community structure. Similar patterns are expected for seasonal differences and disease states. These fundamental differences in microbial communities could be associated with host responses to changing environmental conditions and could influence oyster fitness and overall population health.

80-6 GUINDRE-PARKER, S; Kennesaw State University; *sguindre@kennesaw.edu*
Revisiting glucocorticoid plasticity
Endocrine systems are by definition dynamic and flexible, characterized by carefully regulated circulating ligands that control changes in physiology, development, and behavior across altered intrinsic or extrinsic conditions. Glucocorticoids are thought to be an important coping mechanism for vertebrates facing changes in their environments, as these hormones promote adaptive responses following both predictable and unpredictable environmental perturbations. Glucocorticoid plasticity – the ability of one individual to alter circulating glucocorticoids or other components of the hypothalamic-pituitary-adrenal-axis (HPA-axis) across a gradient of environmental conditions – is thought to be central to the ability of organisms to cope with rapid changes in our dynamic world. The HPA-axis and circulating glucocorticoid concentrations represent complex traits, however, and this complexity needs to be explicitly incorporated into future work on glucocorticoid plasticity. I will outline different types of glucocorticoid plasticity and review previous work on the topic. I will discuss statistical tools which can enable us to quantify individual variation in glucocorticoid plasticity as well as explore the fitness consequences of this variation. Finally, I will discuss the implications of variation in endocrine plasticity for predicting coping ability within and across populations and species.

137-3 GUMM, JM*; STANTON, M; FEUERBACHER, OG; Ash Meadows Fish Conservation Facility, USFWS; *jennifer_gumm@fws.gov*
Refuge Populations as Research Populations: Morphology, Reproduction and Ecology in a Captive Population of Devils Hole Pupfish
Captive populations are critical to the recovery and maintenance of biodiversity of many species. These populations can also provide opportunities for research that bridge gaps between academics and agencies. The Ash Meadows Fish Conservation Facility (AMFCF) houses a refuge population of the endangered Devils Hole pupfish (*Cyprinodon diabolis*) in a 100,000-gallon refuge tank designed to mimic the extreme desert habitat and ecosystem of Devils Hole. One challenge in previous captive populations is exact matching of environmental parameters, which is thought to have altered morphology and behavior of C. diabolis in captivity. The habitat at the AMFCF represents a change in approach to captive environment design, providing increased control and monitoring of biotic and abiotic variables and allowing us to examine the relationships between these variables and fish morphology, behavior and ecology. Herein, we present findings of studies comparing morphology, reproduction and ecology between the captive and wild populations. Specifically, we evaluate larval and early life stage growth rates, reproductive outputs, and report a novel predator-prey relationship that may be mediated by temperature. Taken together, our studies support the integration of research and management as conservation actions often require an understanding of organismal form and function to be successful.

60-5 GURGIS, GP*; DAZA, JD; BRENNAN, IG; HUTCHINSON , M; BAUER , AM; OLORI, JC; SUNY Oswego, Sam Houston State University, The Australian National University, South Australian Museum, Villanova University; *ggurgis@oswego.edu*
Using your head! Finite Element Analysis of head-first burrowing Pygopodids (Gekkota)
Pygopodids are limb-reduced, miniaturized geckos found across Australia and New Guinea. Pygopodids are mainly terrestrial; however, Aprasia species are highly fossorial and further miniaturized, converging on similar ecology and morphology to typhlopid snakes. Additionally, Aprasia from eastern/central and western Australia exhibit distinct skull shapes, possibly due to the functional demands of burrowing in different soil types. Another pygopodid genus, Ophidiocephalus, also was described as fossorial with morphology most similar to eastern Aprasia species, and thus may experience a similar pattern of cranial stress when digging. The burrowing mechanics of pygopodids have never been studied; however, we propose that mechanical stress is distributed outwardly as a shell across the expanded nasals, rather than along an anterior-posterior central column as suggested for other head-first burrowing squamates. To test how differences in morphology may be related to differing functional demands, Finite Element Analysis was implemented by applying and comparing both face loads and point loads of 20N onto 3D solid meshes of the skulls of one eastern/central and one western Aprasia, and one Ophidiocephalus. The resulting stress and strain were low in all taxa and appeared to be evenly spread out across each axis; however, Ophidiocephalus experienced slightly higher average stress than either Aprasia. Although anatomically divergent, each lineage appears to have independently converged on a similar level of biomechanical performance.

S7-10 GUST, KA; US Army, Engineer Research and Development Center, Environmental Laboratory, Vicksburg, MS; *kurt.a.gust@usace.army.mil*
Omics in Non-Model Species: Closing the Loop Among Genes, Molecular Systems, and Phenotypes to predict Adverse Outcomes to Environmental Stress
Omics technologies have been instrumental in characterizing the impacts of environmental stressors and stressor combinations in non-model species of concern to the US Army. The use of omics investigations has provided mechanistic and systems-level understanding of stressor impacts for species ranging from birds, lizards and amphibians to fish and coral. Recent results include functional transcriptomics expression correlations with clinical toxicological phenotypes in Western fence lizards which demonstrated the remarkable robustness of immune responses to lizard malaria infection under combined stressor exposures to food limitation and trinitrotoluene exposures. Additionally, meta-transcriptomics investigations among coal and commensal algal zooxanthellae coupled with histochemical analyses indicated heightened sensitivity to 1,3,5-trinitro-1,3,5 triazine (RDX) exposure in the zooxanthellae compromising energy production within the coral holobiont. As a final example, transcriptomics, proteomics, lipidomics and *in vitro* assays conducted across non-model species (birds and fish) and model species (rodent and human) were integrated to establish a robust Adverse Outcome Pathway (AOP) connecting molecular initiating events, key metabolic, cellular and physiological events to the adverse outcomes of lethargy and weight loss caused by nitrotoluene exposure; the mechanisms of which had remained elusive for over 100 years prior. Overall, omics-based experimental investigations have accelerated expression-to-phenotype discoveries in stressor biology providing unprecedented robustness in systems-level screening for non-model organisms.

138-4 GUSTISON, ML*; PHELPS, SM; University of Texas at Austin, Austin, TX; *gustison@utexas.edu*

Vocal activity is coupled to partner proximity and mating during pair-bonding in a monogamous rodent

Prairie voles (*Microtus ochrogaster*) are one of the few mammalian species to form stable attachments, or pair bonds, between mating partners. A great deal is known about the function of vole tactile social behaviors (e.g., mating, huddling) in establishing pair bonds, but the role of conspicuous behaviors like ultrasonic vocalizations (USVs) remains a mystery. Here, we quantify the temporal dynamics of vocal activity during pair-bond formation and map these dynamics onto other measures of affiliation like partner proximity and mating. Following 4-5 days of social isolation, subjects were paired with either a familiar same-sex sibling or a novel opposite-sex mating partner for up to 22h while we continuously tracked their movements and vocalizations. For both sibling and mating pairs, time courses of vocal activity and partner distance were strongly correlated in that higher USV rates occurred when pairs were separated. Moreover, mating pairs produced higher USV rates than sibling pairs, with peaks in vocal activity linked to the male initiation of mating. Preliminary results reveal that USVs associated with mating are acoustically distinct from USVs that occur when isolated, suggesting that USVs can function both as courtship signals and contact calls. Taken together, our results suggest that prairie vole USVs function to re-establish contact with social partners and promote mating interactions that are critical for pair-bond formation.

S7-11 HAHN, DA; HAHN, Daniel; University of Florida; *dahahn@ufl.edu*

Combining 'omics Approaches to Pick Apart the Genetic and Physiological Architectures of Seasonal Adaptation

The ability of ectotherms to perform under seasonally relevant thermal stress has been a major and active sub-field within biology for >50 years, providing much insight into subjects ranging from adaptation and diversification to risk of establishment of invasive species and predicting winners and losers in the face of climate change. Given the importance of ectotherm thermal biology, there have been many efforts to build bridges between genotypes and seasonal phenotypes. We have learned many seasonal traits are the product of genotype x environment interactions, with strong layers of reversible plasticity for each trait. Yet, there are a wide diversity of results with respect to how selection shapes the genetic and physiological architectures of ectotherm seasonal responses. Even within a single population the genetic architecture and physiological traits implicated in seasonal adaptation vary substantially based on the context in which whole-organism phenotypes are studied. This wide diversity of results, often with discordant conclusions, currently hampers the development of general rules for ectotherm thermal and seasonal adaptation. Here I argue that an integrative biology perspective, with specific focus on carefully defining whole organism performance traits at a sub-organismal level is needed to ensure that equivalent seasonal traits are being considered, so genotype-phenotype mapping efforts across laboratories and systems are in fact comparing apples to apples to bridge the gap between genotypes and phenotypes.

19-1 HALANYCH, KM*; LI, Y; TASSIA, MG; WAITS, DS; BOGANTES, VE; DAVID, KT; Auburn University; *ken@auburn.edu*

The Genome of Deep-Sea Seep-Dwelling Lamellibrachia luymesi (Siboglinidae) and Clues on Chemosynthetic Symbiosis

The long-lived gutless tubeworm *Lamellibrachia luymesi* (Siboglinidae) is found at deep-sea cold seeps in the Gulf of Mexico and has served as model to study chemosynthetic symbiosis and adaptation to extreme environments. However, the evolution of genomic and molecular mechanisms involved in such symbiosis is poorly understood. Here, we present and characterize the genome of *Lamellibrachia luymesi*. In relation to chemoautotrophy, we found evidence that symbionts compensate for the host's deficiency in amino acid biosynthesis and found a large expansion of hemoglobin B1 genes (these genes may function in sulfide-binding to help feed the endosymbionts). Comparative analyses suggest the Toll-like receptor pathway may be essential to host immunity and tolerance/sensitivity to symbionts and pathogens. Last, we identified genes that potentially play an important role in organismal longevity.

40-1 HALE, ME*; GOOLSBEE, AW; University of Chicago, Chicago IL; *mhale@uchicago.edu*

Substrate-based locomotion in young octopuses.

Young *Octopus bimaculoides* (less than 60 days post-hatching) have well developed arms and arm-based locomotor movements. Using high-speed imaging and kinematic analyses we describe substrate associated locomotor movements in 20 young octopuses striding across a glass tank bottom. A variety of patterns of arm movement were observed for both straight movement and change in locomotor trajectory. Several key findings are that: 1. Through use of different arm combinations hatchling octopuses change movement direction without changing the orientation of the body. This has been described previously in mature *O. vulgaris* (Levy et al. 2015. *Current Biology*, 25:1195). 2. Leading arms were most likely to drive locomotion while trailing arms were regularly, but not uniformly, held above the tank floor. 3. The animals used a range of patterns of arm coordination but several were particularly prevalent. Frequently three or four arms positioned on the side of the body in the direction of movement appeared to power locomotion. We recorded several different patterns of arm coordination during locomotion. When three arms were predominantly used, we observed the central arm to alternate extension cycles with the arm to each side. We also observed cases in which the three arms moved in sequence, without synchronous placement of two arms. When four arms were used, at times the center two were observed to move synchronously and alternate with the arm to each side of the central pair while we also saw sequencing of the four arms without synchronous movement of any subset of the arms. We did not observe rhythmic bipedal locomotion, which has been described in other octopus species.

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98-4 HALE, HJ*; POKORNY, L; GARDNER, EM; SLIMP, M; JOHNSON, MG; Texas Tech University, Center for Biotechnology and Genomics, Madrid, Case Western University; *haley.hale@ttu.edu*

Developing a cost-effective workflow for high-throughput targeted sequencing of herbarium specimens using Angiosperms353

The reduced cost of high-throughput targeted sequencing, along with new "universal" probe sets like Angiosperms353, means genomic-scale data is no longer limited to heavily funded laboratories. However, the feasibility of targeted sequencing for population genetics has not been fully explored. Here, we look at the costs and challenges of producing target-capture datasets from herbarium specimens to answer within-species questions in a variety of flowering plants. We describe best practices for choosing methods for DNA extraction, use of enzymatic fragmentation, high-throughput library preparation, and sequencing platform using the Angiosperms353 probe set for enrichment of hundreds of nuclear genes. Our dataset includes herbarium specimens from 24 angiosperm species collected during a survey of Guadalupe Mountains National Park between 1971 and 1974. The variety and age of the specimens brings their own challenges to large scale processing, especially DNA extraction due to the presence of different foliar or floral compounds as well as the diverse tissue composition used. Using Angiosperms353, we observed a 15-20% median enrichment efficiency and that 25000 reads on target was enough to recover over 200 genes. We also consistently recovered the same genes within species. In addition to the targeted genes, we successfully captured flanking noncoding regions, effectively doubling the amount of variable characters that have potential use for population level studies. By optimizing and generating a detailed protocol and cost calculator for sample processing, we offer a strategy for wide adoption of target capture sequencing for both phylogenetics and population genetics.

88-5 HALL, R P*; MUTUMI, G L; HEDRICK, B P; YOHE, L R; SADIER, A; DAVIES, KTJ; DáVALOS, L M; ROSSITER, S J; SEARS, K; DUMONT, E R; University of California, Merced, Louisiana State University, Yale University, University of California, Los Angeles, Queen Mary University of London, Stony Brook University; *rhall8@ucmerced.edu*

Ancestral Generalization as a Potential Gateway to Rapid Dietary Divergence in Neotropical Leaf-Nosed Bats

Neotropical leaf-nosed bats (Phyllostomidae), as a result of adaptive radiation, are a prime example for studying the evolution of sensory morphology. They exhibit diverse and unique feeding strategies among bats. Using diceCT scans of 79 specimens, representing 35 species of phyllostomids and 10 outgroup species, within the superfamily Noctilionoidea, we analyzed the link between volumes of three sensory structures (olfactory bulb, orbits, and cochleae) and diet. We hypothesized that frugivory and nectarivory are associated with enlarged olfactory bulbs and orbits. We predicted that the sensory profile of modern plant-eating bats first appeared in the ancestral phyllostomid. We found that only frugivory is linked to large olfactory bulbs and orbits. The phyllostomid ancestor had larger olfactory bulbs and orbits than its ancestor and outgroups. This study shows that an ancestral shift in sensory morphology associated with diet predated, and possibly enabled, the diversification seen in Phyllostomidae.

17-2 HALL, BE*; BIGMAN, JS; BEDORE, CN; Georgia Southern University, Simon Fraser University; *bh06426@georgiasouthern.edu*

Allometric relationships in the visual ecology of sharks

Adaptations of visual systems, such as acuity, sensitivity, and eye size (e.g., eye diameter) can be used to infer the relative importance of vision to an organism. The high metabolic cost of visual system development and maintenance suggests that large relative eye size (as it relates to body length) may have a significant ecological or evolutionary role. Elasmobranchs are morphologically diverse and inhabit a wide range of marine and freshwater niches. As energetic and ecological demands shift over time, several species occupy different predatory niches across their lifetime, yielding a large array of visual habitats. Additionally, eye size changes with body length ontogenetically, thus elasmobranchs represent an ideal group for examining scaling relationships (i.e., eye growth rate and eye size at a given body length) with respect to specific ecological lifestyle traits. Here we quantified the relationship of eye size and body length in 16 shark species and compared this scaling across species that differ in ecological lifestyle (i.e., activity level, habitat, and maximum size). Relative eye size at a given size varied across species and habitat, but not activity level or maximum size. Deep-sea species had the largest relative eye size, followed by oceanic then coastal species. In contrast, the rate at which eye size scaled with body length was the same across 13 of the 16 species and did not differ with ecological lifestyle trait. These results suggest that ecology may influence relative eye size and not the rate at which eye size scales with body length. As habitat had the greatest influence on relative eye size, future investigations should focus on ecological lifestyle traits involving visual habitat characteristics such as light level, turbidity, and migratory patterns.

105-1 HALL, MI*; PLOCHOCKI, JH; SOSA, JRR; VOEGELE, GM; Midwestern University, AZ, University of Central Florida, Dartmouth College, NH; *mhallx1@midwestern.edu*

The evolution of cutaneous muscles in placental mammals

Four ventrolateral muscular layers consistently support the thorax and abdomen of most tetrapods, while only two muscular layers support the perineum. However, many, if not all, placental mammals have four ventrolateral muscular layers supporting the perineum, that function to allow precise muscular control of the structures that develop as part of full septation of the cloaca into urogenital and anorectal portions, including the rectum, anal canal, urethra, vagina, vulva, and paired vascular erectile tissues. The organization and function of muscular layers of the thorax and abdomen are conserved across taxa, with the muscular layers of the perineum serving a diverse set of functions and are more varied in structure. From superficial to deep, the perineal subcutaneous layer usually regulates orifice closure; the external layer usually supplements erectile and micturition function; the internal layer usually provides primary micturition and defecation regulation, and the transversus layer provides structural support for pelvic organs. However, we observe that some well-known muscles that are present across many mammals may derive from alternative muscle layers. In carnivorans, the retractor penis/clitoris muscle is derived from the external layer, but in ungulates, retractor penis is derived from the transversus muscle. In dogs, constrictor vulvae and constrictor vestibulae are both derived from the external layer, whereas in horses it is derives from the subcutaneous layer and constrictor vestibulae is derived from the external layer. We identify perineal muscular homologies and analogies in a variety of placental mammals, and suggest variations in perineal muscle layering taxa likely represent independent evolutionary adaptations that serve specific reproductive and excretory functions.

98-2 HALSEY, MK*; STUHLER, JD; BRADLEY, RD; STEVENS, RD; RAY, DA; Texas Tech University, Texas Tech University and Museum of Texas Tech, Texas Tech University and Museum of Texas Tech, Texas Tech University ; *michaela.k.halsey@gmail.com*

Temporal and Spatial Genetic Assessment of a Natural Metapopulation

Metapopulation theory is concerned with local population dynamics, especially migration, and the relationship between population colonization and extinction. It is hypothesized that isolated subpopulations with low immigration rates display reduced genetic variation, likely a result of genetic drift. Fortunately, researchers can use genomic sequence data to rigorously examine the population biology and ecology of natural metapopulations in a conservation context. Here, we analyze the genetic variation of 65 samples of a threatened kangaroo rat, *Dipodomys elator*, using 3RAD, a modified restriction site associated sequencing approach amenable to low initial DNA input, such as those sampled from minimally invasive techniques or degraded samples. We demonstrate that there are at least two *D. elator* subpopulations, which are grouped into eastern and western demes. An area where no samples were drawn, called a "sampling hole," separates these two. In addition, this metapopulation exhibits an excess of heterozygotes, which is symptomatic of small, isolated populations experiencing coalescence. Because of these results, we classify the *D. elator* population as a classic two-population metapopulation whose persistence is dependent on deme location. Since subpopulations can vanish very rapidly, it is vital for conservation managers to monitor spatial population dynamics and genetic variability of this species for long-term population viability.

61-1 HAMMOND, KA*; DOLAN, JE; SAWAYA, M; University of California Riverside; *khammond@ucr.edu*

Deer Mouse Lungs as Flexible Environmental Interfaces

Because of the flexible and fast growing tissues in their digestive tracts, many animal species are able to respond to increases in metabolic demands by increasing the surface area available to increase absorption of nutrients in their gut. They can also reduce energy expenditure by reducing tissue amount in times when food availability decreases. In this way the intestinal tracts of animals are highly flexible and responsive interface to the outside world. My lab has been investigating whether or not the respiratory interfaces in mammalian lungs have an ability for a plastic response that is driven by demand that is similar to mammalian guts. In this case, rather than changes in caloric density, we have been examining the effect of low oxygen tensions on the respiratory membranes and daily energy expenditure of deer mice (*Peromyscus maniculatus*) living at high altitude. Deer mice are interesting because they live at and move between altitudinal extremes during their life time and are, thus, exposed to a variety of oxygen tensions. In recent work we have found: 1. high altitude acclimated deer mice display an increase in oxygen transport tissue and alveolar septal tissue relative to the low altitude acclimated mice. 2. Likewise, in a different set of experiments we have learned that the bulk amount of oxygen that is transported across the alveoli to the blood increases in the lungs of high altitude mice relative to low altitude mice. 3. Finally, we have learned that, upon acclimation to high altitude, mice given running wheels are able to substantially increase their daily energy expenditure relative to the same expenditure with running wheels before acclimation. Taken together these several experiments have demonstrated that the lungs of deer mice are somewhat flexible and are able to support change metabolic demands in very harsh environments.

1-7 HANEY, WA*; STROTHER, JA; University of Florida; *haneyaustin@gmail.com*

Time to Panic? Stressors modulate exploratory behavior in larval zebrafish

The stress response of vertebrates can be initiated by many different environmental stimuli including extreme temperatures, noxious chemicals, mechanical disturbance, visual stimuli and pain. These sensory inputs are integrated within the central nervous system (CNS), which then drives responses in the peripheral nervous and endocrine systems. Catecholamines and cortisol are released into the blood, resulting in a cascade of physiological changes that includes shifts in heart rate, blood pressure, and plasma glucose levels. Although the physiological effects of stress have been well-studied, the mechanisms by which stress modulates CNS activity and alters behavioral responses are not well understood. Zebrafish larvae are an ideal organism in which to examine this question, since they are very well-suited to most behavioral and neurobiological methods. Larval zebrafish exhibit a weak preference for well-lit areas, and previous studies have suggested that stress modulates this behavior by enhancing light preference. We conducted a broad survey of this behavior in order to identify the features of the visual stimulus that affect this behavior, the specific kinematic changes that produce the observed light preference, and the effects of specific stressors (electric shock, noxious chemicals) on responses. Our results suggest that stressors produce characteristic changes in light preference and exploratory behavior. We then used multiphoton *in vivo* calcium imaging to identify neuronal populations in the hindbrain associated with stressful stimuli, and small-molecule blockade to identify neuron types necessary for stress-induced changes in behavior. Our results suggest a simple pathway for stress-induced modulation of exploratory pathway.

S2-1 HANSON, H; MARTIN, LB; STEVENSON, TJ*; University of South Florida, University of Glasgow; *tyler.stevenson@glasgow.ac.uk*

Introduction to Epigenetic Variation in Endocrine Systems

Predictable variation in environmental cues provide reliable information that animals can use to time life-history transitions. Endocrine systems have evolved in part, to maintain a consistent internal milieu and coordinate organism-wide physiological responses to environmental changes. An emerging body of evidence reveals that epigenetic modifications are central to timing genome plasticity that underlies adaptive and maladaptive endocrine responses. The symposium includes a series of presentations that will discuss the latest findings on epigenomic plasticity with a focus on range expansions, ecology and life-history transitions. This introductory presentation will provide an overview of developmental, transgenerational and rhythmic epigenetic modifications with an emphasis on DNA methylation and histone modifications. Then a brief introduction of the symposium speakers and their research programs will be provided. Overall, the aim of the presentation is to ensure that the topics covered in the symposium will be accessible to all attendees regardless of their experience with epigenetic modifications.

S2-2 HANSON, HE*; WANG, C; SCHREY, AW; JIANG, RHY; MARTIN, LB; University of South Florida, Global and Planetary Health, Georgia Southern Armstrong Campus, Department of Biology; *haleyhanson@mail.usf.edu*

Epigenetic Potential and DNA Methylation Across an Ongoing Avian Range Expansion

During range expansions, epigenetic mechanisms may mediate phenotypic responses to environmental cues, enabling organisms to adjust to conditions at novel sites. In particular, we expect that the number of CpG sites within the genome, one genetic mechanism underlying epigenetic potential, may be important for success at range edges because methylation could titrate gene expression contingent on environmental conditions. Previously we found that this form of epigenetic potential was higher in introduced compared to native populations of house sparrows (*Passer domesticus*) for two immune genes (Toll-like receptors *2A* and *4*). Here, we took a next-generation sequencing approach (ddRadSeq and EpiRadSeq) to investigate how this same form of epigenetic potential, as well as resultant DNA methylation, varied across five sites in the ~60 year-old Kenyan house sparrow range expansion. We found that CpG sites increased towards the edge of the invasion, even when accounting for genetic diversity among sites. This pattern was driven by more losses of CpG sites in birds from the core. Additionally, DNA methylation levels towards the range edge, when we considered only sequences proximal to CpG sites that were lost to mutation in core birds. This pattern is significant because DNA methylation across the whole genome decreased towards the range-edge. These results provide further evidence that epigenetic potential influences house sparrow range expansions, perhaps providing greater phenotypic plasticity later to be assimilated genetically in as populations adapt to new conditions.

91-6 HARRIS, BN*; PRATER, CM; LOCKWOOD, R; KENNEDY, A; CARR, JA; Texas Tech University, Texas Tech University ; *breanna.n.harris@ttu.edu*

Now You See It, Now You Don't: Role of Tectal CRF Administration on Visually Guided Feeding Behavior

Navigation of feed vs. flee trade-offs is crucial for survival and fitness. To do this animals must integrate sensory and somatic information. The optic tectum (OT) integrates visual and lateral line information and sends projections to the brain stem and spinal cord, thus it may link sensory cues with motor output. The precise cues and neuromodulators of this trade-off are not entirely known, but neuropeptides associated with the physiological stress response may play a role. CRF, well known for its role in the hypothalamic-pituitary-interrenal axis, is abundant in the OT. In the South African clawed frog (Xenopus laevis) stressor or predator exposure decreases feeding and increases OT CRF, and elevated OT CRF decreases feeding; blocking CRFR1 reverses outcomes. The CRFR1 may be acting on visual, lateral line, and/or multiple sensory modalities. In the visual system, CRF may alter the way food items are perceived. Here, we test the prediction that OT CRF injection will decrease the response to visual stimuli. We initially tested multiple releasing stimuli previously used in adult frogs before finding a purely visual stimulus (iPad) that repeatedly elicited behavioral responses in juveniles. Frogs were injected with one of 4 doses of CRF, saline, or left unmanipulated; 1 h later they were exposed to visual prey cues (iPad movie) and then to a live worm (positive control). After 72 h, behavioral tests were repeated. All trials were video recorded. Analysis of discrete behaviors is underway. Preliminary analyses suggest CRF decreases the response to visual stimuli, and to live prey, but does not completely abolish responses. Our data will aid in understanding the neuroendocrine mechanisms governing feed/flee trade-offs. Funded by the NSF (Grant No. 1656734).

17-1 HARRIS, OK; KINGSTON, ACN; STEICHMANN, NR; JOHNSEN, S; SPEISER, DI*; University of Cincinnati, University of South Carolina, Duke University; *dispeiser@gmail.com*

How and why are the blue eyes of scallops blue?

Many animals produce structural colors, but taxa vary in how and why they do so. Scallops, for example, have dozens of mirror-based eyes and, in some species, these eyes are a bright iridescent blue. In other species, the eyes are a non-iridescent brown or black. We hypothesized that the blue eyes of scallops obtain their color, at least in part, from the scattering of short-wavelength light by photonic nanostructures. Using transmission electron microscopy, we found the epithelial cells surrounding the blue eyes of the bay scallop *Argopecten irradians* contain close-packed nanospheres that are absent from the black eyes of the sea scallop *Placopecten magellanicus*. The nanospheres in the eyes of *A. irradians* are ~ 180 nm in diameter and consist of electron-dense cores ~ 140 nm in diameter surrounded by less electron-dense shells 20 nm thick. These core-shell nanospheres are packed at a volume density of ~ 60% and energy-dispersive X-ray spectroscopy indicates they are not mineralized. Using optical modeling, we calculated that the nanospheres in the eyes of *A. irradians* are an ideal size for producing angle-weighted scattering that is bright and blue. From these results, we have learned how scallops make their eyes blue, but we have yet to learn why they do so. We hypothesize that light-scattering nanospheres help prevent UV wavelengths from damaging the internal structures of the eyes of blue-eyed scallops. If we are correct, we would expect to see a correlation between eye color and habitat depth across scallops, with blue-eyed species tending to live in shallower, more UV-rich environments than black-eyed species. To test our hypothesis, we used comparative phylogenetic methods to ask if eye color in scallops correlates with environmental features related to light conditions, such as depth.

79-1 HARRIS, RM*; AUSTIN, SH; LANGCALISI, A; MACMANES, M; CALISI, RM; NPB, UC Davis, MCB, UNH, MCB, UNH; *rmharris@ucdavis.edu*

Peaks and valleys of prolactin-related gene expression during the pigeon parental care stage

Parental care of offspring is essential to maximize fitness in many species throughout the animal kingdom. New parents undergo major changes in physiology and behavior to promote offspring survival in predictable and unpredictable conditions. While much is known about neuroendocrine mechanisms modulating these changes, we know less about genomic mechanisms driving these changes in male and female parents. To fill this gap, our team characterized gene expression states of the hypothalamus, pituitary, and gonads of mothers and fathers of the socially monogamous, bi-parental rock dove (*Columba livia*) at multiple stages of parenting. Next, we manipulated the timeline of the offspring development to distinguish genomic signatures that are driven by external cues from the offspring from internal cues from within the parent. We developed an R workflow for rapid and reproducible hypothesis testing related to specific tissues, sexes, and timepoints from our dataset of 1000 samples. Data and analyses are available at https://github.com/macmanes-lab/DoveParentsRNAseq. Preliminary findings suggest that gene expression of hundreds of genes in the pituitary mirrors that of circulating prolactin levels in the blood. Removal of offspring around the time of chicks hatching causes circulating prolactin to plummet and gene expression patterns shift to a non-parental state; however, prolonging incubation or delaying hatch has a much more subtle effect on gene expression. By characterizing and manipulating parental care and measuring the effects on hormones and gene expression in both male and female parents over time, we provide a more complete picture of how the hypothalamic-pituitary-gonadal axis responds to predictable and unpredictable changes during offspring development.

77-7 HARRISON, J.F*; AIVAZIAN, V.; WEED, M.; MUNOZ, E; VANDENBROOKS, J.M; Arizona State University, Midwestern University; *j.harrison@asu.edu*

Hypermetric scaling of the leg tracheal system in cockroaches

Understanding the causes and consequences of evolution of larger or smaller body sizes in a lineage remains one of the important challenges of evolutionary biology. Insects have an unusual (for animals) respiratory system, transporting oxygen in the gas phase via air-filled tracheae. How is the morphology of the tracheal system adjusted as insects vary in 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, ranging in mass from 0.5 to 4 g. Animals were imaged at Argonne National Laboratories using x-ray synchrotron imaging, all with the same resolution (0.65 microns/pixel). Composite images were created by tiling, and we measured tracheal diameters and the fraction of body volume by point-counting using ImageJ. Tracheal diameters generally scaled isometrically, as did the percent of body volume occupied by the tracheal system within the head, thorax and abdomen. However, within the leg, tracheal volume scaled strongly hypermetrically, due to an increase in the number of tracheae with size. The length of meta- and meso-, but not prothoracic legs scaled hypometrically. These data indicate that evolution of larger species size in cockroaches requires specific modification of the tracheal system structure of the legs, perhaps to overcome the challenges of long-distance transport through these long, blind-ended structures. The increased tracheal content of legs in larger roaches will also reduce leg density, likely reducing cost of transport and risk of damage. Supported by NSF IOS 1122157 and IOS 1558052.

14-6 HARRISON, JS*; PORTER, ML; PATEK, SN; Duke University, University of Hawai'i, Manoa; *jacob.harrison@duke.edu*

Scaling and development of elastic mechanisms: the tiny strikes of larval mantis shrimp

Mantis shrimp use a latch-mediated spring actuation (LaMSA) mechanism in their raptorial appendages to produce powerful strikes for resource acquisition and defense. Previous research on the mantis shrimp strike, including kinematics and appendage morphology, has focused exclusively on the adults (3-30 cm total length). However, mantis shrimp first exhibit striking behavior during their larval stages (~3 mm total length). At this size, mathematical models suggest that spring driven motion may not be an effective way of actuating the mantis shrimp strike. Understanding the larval mantis shrimp strike allows us to address major questions regarding the scaling and development of LaMSA systems. Here we describe the larval mantis shrimp strike in *Gonodactylaceus falcatus*, including raptorial appendage development, morphology, and kinematics. We raised *G. falcatus* collected as eggs in Honolulu, Hawaii to their seventh larval stage. Using light and scanning electron microscopy we show that larval *G. falcatus* possess the saddle and meral-v as early as their fourth larval stage. Using a custom designed apparatus, we captured high speed video of strikes from fourth and fifth stage larvae. Larval mantis shrimp achieved, on average, rotational accelerations of $6.5x10^5 \pm 5.1x10^5$ rad/s^2 with an angular velocity of 350.1±159 rad/s (12 animals, 26 strikes). When comparing strike kinematics from larvae to various adult mantis shrimp species, we find larvae achieve similar angular accelerations as adult mantis shrimp. Establishing the development of the raptorial appendage and strike kinematics in larval mantis shrimp offers insights on the development of LaMSA morphology, and how size may limit LaMSA mechanisms.

S7-5 HAVIRD, JC; The University of Texas, Austin, TX; *jhavird@utexas.edu*

Building Bridges from the Mitogenome to the Mitophenome to the Organismal Phenome

Phenotypes do not emerge solely as a result of variation at a single locus, but can be altered by genetic variation at other loci (epistasis), environmental variation (plasticity), and epigenetic modifications. Complicating matters further, most studies only consider the nuclear genome when examining genotype-to-phenotype relationships. However, emerging evidence suggests mitonuclear epistasis is rampant – different phenotypes arise when the same nuclear genome is placed against different mitochondrial genotypes. The environment can further modify mitonuclear epistasis (G x G x E interactions). "Phenotype" can also be defined across biological scales, from the expression of genes to whole-organism fitness. In this talk I will discuss a series of studies linking mitochondrial genotype to mitochondrial and whole-organism phenotypes. First, we ask whether extreme variation seen in mitochondrial genomes of the angiosperm genus *Silene* affects mitochondrial function, despite having little noticeable effects at the organismal level. Next, we explore whether placing different mitochondrial genotypes against a common nuclear genome affects mitochondrial function and organismal phenotypes in *Silene*. Finally, we present a meta-analysis of mitochondrial and whole-animal oxygen consumption in response to temperature to ask how similarly phenotypes at different scales vary in response to environment. Taken together, our results suggest that phenotypic variation should be explored in response to genetic variation at both mito- and nuclear loci, across environments, and across biological scales.

S4-11 HAWKES, K; University of Utah; *hawkes@anthro.utah.edu*

The centrality of grandmothers in human evolution

When RA Fisher, PB Medawar, GC Williams, and WD Hamilton laid the foundations of evolutionary life history theory, they recognized elements of what became a grandmother hypothesis for the evolution of human longevity. Only subsequent study of modern hunter-gatherers, great apes, and the wider mammalian radiation revealed strong regularities in development and behavior that identify additional unexpected effects that grandmothering likely had on human evolution. Now ancestral grandmothering is a serious contender to help explain not only, 1) the large fraction of post-fertile years women live, but also 2) the pair bonding habits that distinguish humans from our closest living evolutionary cousins, the great apes (and most other mammals), 3) our big human brain and large neocortex, 4) our socially precocious babies' active engagement with others, and 5) our preoccupation with reputations, shared intentionality and persistent cultural learning, which 6) underpin the diversity of our cultural lives, and even 7) that particular human distinction: language. Ancestral grandmothers' contribution to the ancestry of subsequent generations likely contributed to an astonishing array of features that make us human.

65-4 HAWKINS, RK*; STOCKER, MR; METZGAR, JS; Virginia Tech; *rehawk@vt.edu*

The Importance of Natural History Collection Clubs in Preserving and Using University Collections

Natural history collections have an essential place in universities for education, research, and outreach. For example, collection specimens are used in taxonomy courses, biodiversity studies, and scientific communication. However, despite these valuable and well-established uses, many university collections are neglected from a lack of funds and attention, sometimes even to the point of ruin. The Natural History Collections Club Network (NHCCN) was founded in 2013 to save and advocate for collections like these through the establishment of Natural History Collections Clubs (NHCCs) at their universities. Currently, NHCCs have been formed at Arkansas State University, University of California at Santa Barbara, University of California at Riverside, Virginia Tech, University of New Mexico, Georgia Southern University, and UNC Wilmington. NHCCs have been successful in bringing student attention to university collections, which in turn has provided collection volunteers; increased specimen use in education, research, and outreach; and even led to much-needed funding opportunities. At Arkansas State University, NHCC members raised funding and worked to revitalize forgotten teaching collections by rehousing specimens, improving collection spaces, and hiring student workers. At Virginia Tech, student interest in natural history grew after a NHCC was founded, leading to the creation of a museum studies course. These accomplishments and many more from other NHCCs illustrate their power to bring funding and attention back to university collections, allowing them to continue serving students, researchers, and the community.

19-3 HAYNES, L; BEVERIDGE, J; FISH, O; GIAMBRONE, SA; REED, L; SCOTT CHIALVO, C*; University of Alabama, Appalachian State University; *chialvoch@appstate.edu*

Characterizing the Impact of a Complex Mix of Toxins on Survival in Drosophila Species

To defend against herbivory, plants and fungi produce a variety of secondary metabolites. While understanding the biological effects of these host secondary metabolites on plant-insect interactions remains an active area of research, many studies focus on a single metabolite or a subset of the compounds. However, the potent bioactivity of some compounds is due to their synergistic/antagonistic interactions with other metabolites in their natural matrix. Thus, there is a need to characterize plant-insect interactions using complex mixtures that more closely resemble the chemical matrix found in the host. In this study, we examine this question by assessing how the survival of mushroom-feeding *Drosophila* in the *immigrans-tripunctata* radiation is impacted by the natural suite of toxins found in a small proportion of their hosts. Previous work examining toxin tolerance in these flies focused only on the effect of -amanitin; however, the toxic mushrooms contain over 14 known toxins. To assess the impact of a natural toxin mix on survival, we reared the larvae of three tolerant and six susceptible species from the radiation and the distantly related *D. melanogaster* on diets containing differing concentrations of a toxin mix extracted from the host *Amantia phalloides*. To quantify the effect of the natural toxin mix, we measured several fitness phenotypes, including survival to adult and thorax length. Our results demonstrated that tolerant species exhibit similar patterns of survival to a diet containing a single toxin. We also found that the susceptible species could develop on low levels of the natural toxin mix that are lethal to most other Eukaryotes, including *D. melanogaster*. Thus, this study provides context for future research examining the evolution of toxin tolerance.

S4-2 HAYSSEN, V; Smith College, Northampton, MA; *vhayssen@smith.edu*

Misconceptions about Conception and Other Fallacies: Historical Bias in Reproductive Biology

The #meToo movement is a current social meme whose tendrils have not quite crept into our understanding of organismal physiology, behavior, and evolution. But the time has come to do so. For instance, although most consider polar bears solitary, female polar bears live nearly all their lives in the company of their offspring. Female polar bears have constant social interactions with their cubs and their interactions with their environment are as a social group not as an individual. How they hunt, how far they roam, how they thermoregulate, how much they are exposed to pathogens, how much they need to scan the environment for predators, all these aspects of their lives differ from those of a solitary individual. So, why are polar bears usually considered solitary? Why do we devalue the importance of reproduction in our assessment of the biology and ecology of animals? I will provide a brief review of the historical bias in reproductive science, the consequences of that bias, and, more importantly, ways to ameliorate that bias going forward.

55-4 HE, L; SHIN, SHJ; WANG, Z; YUAN, I; WESCHLER, R; KOYAMA, T; NIJHOUT, HF; SUZUKI, Y*; Wellesley College, Wellesley, MA, University of Copenhagen, Copenhagen, Denmark, Duke University, Durham, NC; *ysuzuki@wellesley.edu*

Body size sensing in the tobacco hornworm, Manduca sexta: the role of TGF-beta/Activin signaling in metamorphic timing

How organisms sense their size remains poorly understood. In insects, the final larval instar is specified if they have attained the threshold size; if they have not, they will undergo additional larval molts and continue to grow. In this study, the nature of threshold size determination was investigated using the tobacco hornworm, *Manduca sexta*. Hypoxia treatment caused larvae to have a lower threshold size than those reared on low nutrient diet. Measurements of relative sizes of muscles and fat body showed that the size of the muscles/integuments was correlated with the attainment of threshold size. In addition, we found that the expression of the TGF-beta/Activin signaling gene, *myoglianin (myo)*, was associated with the attainment of threshold size and that its knockdown led to supernumerary molts and prevented metamorphosis. We will present a model for how larvae sense their size.

S11-7 HEALY, SD; University of St Andrews; *susan.healy@st-andrews.ac.uk*

Using Neural Activation to Understand Nest Building in Birds

Nest building is fundamental to successful reproduction for most birds. In spite of its importance, however, rather little is known about the decision making that is involved in building. Indeed, it is still commonly assumed that the nest that is built is the product of an innate template. But there are increasing data to show that learning and memory play a role in a variety of decisions that birds make (including associations between material properties, environmental conditions and reproductive success, and who to copy) when building and there are now also data to indicate which parts of the brain might be activated when birds build. Together the behavioural and neural activation data provide a model for examining the mechanistic bases of physical cognition, including the roles of perception, motor output and a variety of cognitive processes.

S10-1 HEBDON, N*; RITTERBUSH, KA; University of Utah, Salt Lake City; *nicholas.hebdon@gmail.com*

Seeing Spirals: Evaluating the hydrodynamic effect of changes in spiraling morphology of ammonoids

Ammonoid cephalopods are an extinct group that are notable for their 300 million year history dominated by recurrent cycles of diversity boom and bust. Throughout these biodiversity cycles they repeatedly evolve distinct coiling shell shapes. These coiled ammonoids have shown very pronounced morphological shifts during their recovery following bust periods. Paleoecological research into these enigmatic animals, which have no strong modern analogue, has long featured discussions of how these changing shell morphologies influenced swimming ability. Experimental and computational approaches have attempted to quantify the hydrodynamic costs, or benefits, of shell shape, with success distinguishing most relevant first-order parameters. We advance this work by using computational fluid dynamics to investigate the hydrodynamics of theoretical ammonoid morphotypes. We use 3D modeling to create synthetic ammonoid shells that model variation in two key morphological parameters: Whorl expansion (the rate at which an individual coil increases in diameter) and umbilical exposure (the amount of central coiling exposed to flow). We use Ansys FLUENT to resolve the flow fields around each shell and the drag they incur. These drag values are then compared against a control morphotype that represents the centerpoint of each parameter variation. Our results show that the magnitude of change in drag is non-linearly sensitive to both the direction and magnitude of change within a parameter. We also recover a distinct hierarchy of effect between morphological parameters. We present new gradients of these animals swimming potential that, at larger scales, can provide the groundwork for testable hypotheses on the structure of paleozoic and mesozoic marine systems through time.

72-5 HEDRICK, BP*; BROCKLEHURST, N; MITCHELL, JS; BENSON, RBJ; Louisiana State University Health Sciences Center, New Orleans, USA, University of Oxford, Oxford, UK, West Virginia University, Beckley, USA; *bhedri@lsuhsc.edu*

Functional Constraints and Disparity in Bird Limb Proportion Evolution

Birds have wide variation in flight capability, from flightless kiwi birds to hyper-aerial swifts. Their dinosaurian ancestors also show tremendous disparity in limb proportions and locomotor modes, spanning massive quadrupedal sauropods, carnivorous bipeds, and small bipedal herbivores. Key questions about locomotor macroevolution in dinosaurs include whether locomotor innovations were pulsed or gradual, and to what extent increases in locomotor disparity correlate with changes in patterns of integration both between and within limbs. We conducted disparity-through-time and integration analyses on a limb proportion database of 822 species of non-avian dinosaurs, fossil birds, and extant birds spanning 230 million years of evolutionary history. We found a pulse-like pattern with an early increase in relative subclade disparity of limb proportions coincident with the origin of major non-avian dinosaur clades during the Triassic and with the Early Cretaceous radiation of birds. There was a subsequent increase in disparity concurrent with the origin of crown Aves, followed by a large drop in disparity just prior to the end-Cretaceous extinction. Further, we found that shifts between locomotor modes were accompanied by a restructuring of within and between limb integration patterns. Flightless bipeds had moderate integration between limbs and high integration within limbs. In contrast, volant species had high integration within both limbs, but low between-limb integration. These results suggest that dinosaur and bird limb innovations evolved in pulses and that these pulses were strongly correlated with changes in limb integration regimes.

70-6 HEESY, CP; Midwestern University, AZ; *cheesy@midwestern.edu*

On the Laws of Haller and Leuckart OR Does visual resolution scale with velocity and size in animals?

Vertebrate eyes, even with differences due to ecology, (generally) scale hypometrically with body size – as a result of a relationship called Haller's Law. Isometric eye size scaling is, however, predicted for faster-moving animals, in a relationship known as Leuckart's Law. Increased eye size within this context is often interpreted or assumed to be a proxy for higher visual acuity or resolution. Although the axial length of the eye does correlate with visual acuity, studies of birds and mammals conflict in supporting the eye-size-to-velocity relationship, in that it is currently unclear whether faster locomoting animals require higher visual resolution, or if variability in eye size is primarily explained by overall body size. I analyzed data on visual acuity, linear dimensions of the eye, maximum linear velocity, body length, and mass for multiple orders of running and flying insects, mammals, and birds to broadly evaluate the resolution-to-speed relationship. Whereas eye size and velocity do both scale with body-size variables, neither eye size nor acuity scale with speed in any phylogenetic group or locomotor type. Additionally, neither acuity nor eye size matches the empirically observed 'U'-shaped curvilinear relationship between animal body size and speed. This study does not support Leuckart's Law, and I suggest that high visual resolution is not necessarily required for high-speed locomotion.

109-4 HEINE, KB*; JUSTYN, NM; HILL, GE; TUCKER, VL; JUNG, D; POLLOCK, B; HOOD, WR; Auburn University; *kbh0039@tigermail.auburn.edu*

Modeling Mitochondrial Behavior and Morphology from TEM Micrographs of Copepod Myocytes Following Ultraviolet Irradiation

The ability of animals to produce energy is determined largely by the function and structure of mitochondria. To meet the energetic demands of survival and reproduction, an organism must produce energy efficiently in the face of endogenous and environmental stressors. These stressors include exposure to reactive oxygen species that are produced both directly via oxidative phosphorylation and indirectly by environmental factors such as ultraviolet radiation. Such stressors can have negative impacts on mitochondrial function, but they may also increase mitochondrial performance at low levels by acting as cellular signals. Moreover, previous work has shown that ultraviolet radiation not only has negative impacts on the longevity of aquatic organisms but also conveys beneficial reproductive performance early in life. Further work is needed to determine the beneficial and detrimental effects that environmental stressors impose on mitochondrial structure and, therefore, organism performance. This study aims to determine how ultraviolet irradiation affects mitochondrial behavior and morphology in myocytes of the copepod *Tigriopus californicus*, in addition to whole-organism respiratory function. Using transmission electron microscopy and corresponding respiration assays, we address the impact of both moderate- and high-dose ultraviolet-A/B irradiation on the proportion of inter-mitochondrial junctions and density of the inner mitochondrial membrane, as well as mitochondrial density and aspect ratio.

S1-2 HEISER, S*; SHILLING, AJ; AMSLER, CD; MCCLINTOCK, JB; BAKER, BJ; University of Alabama at Birmingham, University of South Florida ; *heiser@uab.edu*

Allies, Cheaters and Thieves: Macroalgal-Mesograzer Interactions on the Western Antarctic Peninsula

Macroalgae dominate the hard benthos along the Western Antarctic Peninsula to depths of up to 40 m or more. Most of the macroalgae are chemically defended from a variety of macro- and mesograzers but harbor very high densities of amphipods. The amphipods benefit from living on the large, chemically-defended macroalgae because they gain refuge from fish which are their primary predators. A majority amphipod species do not consume most of the macroalgal species, but are of benefit to the macroalgae by keeping them relatively clean of epiphytic microalgae and filamentous macroalgae. One amphipod species, however, does consume some of the chemically defended red algal species and is able to sequester algal metabolites for its own use as defenses against fish. A combined genetic and chemical analysis of the alga from different collection sites revealed that it divides into two closely related haplotypes (‘phylogroups'), not distinct enough to be considered separate species, each of which is further divided into one of 14 groups (‘chemogroups') with distinct mixtures of defensive, halogenated secondary metabolites. The amphipods feed on some of the chemogroups at significantly slower rates than others. Different sites are dominated by different chemogroups but experiments indicate that most individual algae retain their chemogroup for at least a year after transplantation between sites. Patterns of gene flow are being investigated as a potential source of the spatial variation in chemogroups.

128-2 HELLMANN, JK*; BENSKY, M; ZIELINSKI, C; ANDERSON, S; BELL, A; University of Illinois, Urbana-Champaign; *hellmann@illinois.edu*

The Evolution of Sex-Specific Paternal Effects in Threespined Sticklebacks

Sex-specific selection pressures can generate different phenotypic optima for males and females in response to changing environments (sex differences in phenotypic plasticity). However, there is growing evidence that the ways in which parental environments alter offspring phenotypes (transgenerational plasticity) can also depend on sex. Sex-specific transgenerational plasticity is potentially of great evolutionary significance, as it is a mechanism by which potentially adaptive traits can persist selectively across generations via only daughters or sons. In previous work, I found that there were sex-specific sperm-mediated paternal effects in response to predation risk in threespined sticklebacks (*Gasterosteus aculeatus*). Here, I explore whether these sex-specific patterns might have evolved during the stickleback radiation. I compared replicate populations of ancestral (marine) and derived (freshwater) sticklebacks that were reared in a common garden. There was population-level variation in the direction of sperm-mediated paternal effects, and evidence for parallel evolution of sex-specific paternal effects during the stickleback radiation. In ancestral populations, sons and daughters responded similarly to paternal cues of predation risk, but in derived populations, sons and daughters responded differently. These phenotypic differences emerged well before offspring were reproductively mature, suggesting that these differences organize in early development. These results suggest that current work seeking to understand the evolution of transgenerational plasticity needs to also consider the conditions which favor the evolution of sex-specific transgenerational plasticity.

33-5 HELMS CAHAN, S*; FRIETZE, SE; GERRARD, DL; BORA, K; KAPLAN, I; PEREZ, M; LOCKWOOD, BL; TEETS, NM; WATERS, JK; AXEN, HJ; University of Vermont, LeTourneau University, University of Kentucky, Providence College, Salve Regina University; *scahan@uvm.edu*

Developmental temperature alters brain gene expression in adult Drosophila melanogaster

The physiology of ectotherms must be able to function across a wide range of environmental temperatures, particularly in thermally variable habitats. When external temperatures are temporally correlated, earlier thermal experiences can lead to a beneficial acclimation response that enhances robustness to future thermal conditions. In *Drosophila melanogaster*, temperatures experienced during larval development can lead to shifts in critical thermal minima (CTmin) of ~1.5°C, and critical thermal maxima (CTmax) of ~0.5°C. Although these whole-body effects are well-described, it is unclear how developmental acclimation produces enhanced thermal tolerance, particularly in the central nervous system, whose failure operationally defines critical thermal limits. We investigated the effect of developmental acclimation on brain gene expression by comparing brain transcriptomic profiles of *D. melanogaster* that were reared from egg through pupation at 18°C, 25°C, or 30°C and then held at 25°C for two days as adults. Developmental temperature impacted a small proportion of genes, with a larger number showing a response to cool rearing temperatures (23) than warm temperatures (2) when each were compared to the control of 25°C. Among these, several were associated with thermal protective functions, including the heat shock response, calcium ion regulation, and phospholipid metabolism. These results suggest that the adult brain may be primed by gene-regulatory changes that are set during development to prophylactically protect against thermally-induced neuronal failure as an adult.

89-6 HENSCHEN, AE*; HAWLEY, DM; ADELMAN, JS; University of Memphis, Virginia Tech; *henschen@memphis.edu*
Oxidative damage resistance as a potential mechanism of disease tolerance in a wild host
Hosts have two main ways to combat parasitic infections: resistance, which lowers pathogen load directly, and tolerance, which decreases the fitness costs of infections at a given pathogen load. Among animals, the mechanisms underlying variation in tolerance are not well understood. Early immune defenses against infection often include the release of free-radicals, which help kill pathogens, but also result in oxidative damage to host cells and tissues, potentially reducing host fitness. As such, minimizing this oxidative damage may be an important mechanism of tolerance in animals. We tested this hypothesis in house finches (*Haemorhous mexicanus*) infected with an emerging bacterial pathogen, *Mycoplasma gallisepticum* (MG). MG spilled over to house finches in the early 1990's in the eastern United States and has since spread to most house finch populations. Previous work in this system suggests that tolerance may be evolving to MG in populations with the longest history of MG endemism, and that more tolerant populations have dampened inflammatory responses. As inflammation and free radical production are intricately linked, oxidative damage may play an important role in producing tolerant phenotypes in this system. In this study, we compared levels of oxidative damage both before and during experimental MG infections among house finches from populations that differ in their tolerance to MG. These populations span the temporal scale of MG endemism, including a population near the original spill-over and a population still naïve to MG. We predicted that individuals from populations that are more tolerant to MG would have a lower amount of oxidative damage than individuals from less tolerant populations following experimental infection with MG. This work represents one of the first investigations into the mechanisms of tolerance in a wild animal host.

135-7 HERBERT, AM*; WILGA, CD; University of Alaska Anchorage; *aherbert3@alaska.edu*
Varied tooth plate shape, varied diet: Morphology of Spotted Ratfish Tooth Plates
Teeth are a critical aspect of feeding in most vertebrates and vary greatly in shape and size among taxa. A tooth can perform multiple functions or be specialized for a specific prey type. The tooth plates of *Hydrolagus colliei*, spotted ratfish (Holocephali), have a narrow occlusal surface and the overall shape of the tooth plate varies within an individual and among species. The occlusal edge varies in the presence and number of sharp points or bumps. Spotted ratfish feed on a variety of hard and soft prey, yet lack the molariform or pavement tooth plates typical of durophagous (feed on hard prey) fish. This study investigated the morphology of the tooth plates of spotted ratfish to quantify the shape variation and describe the material arrangement. Geometric morphometric outline analyses were performed on the tooth plates to evaluate the factors that contribute to shape variation. The principal components that described the majority of shape variation in the tooth plates were the dimension (height or width) and the occlusal edge (smooth vs. pointed). Polarized light microscopy was used to visualize the arrangement of the two materials that form holocephalan tooth plates: hypermineralized dentine arranged as columns of spheres within trabecular dentine. Hypermineralized dentine has a slower wear rate than trabecular dentine, therefore as the relatively softer trabecular dentine wears, leaving the relatively harder spheres as points on the occlusal edge. The spheres eventually wear forming a smooth occlusal edge, after which the cycle starts again. This process is responsible for the variation in tooth plate shape among contralateral elements as well as among individuals and is similar to the self-sharpening teeth of rodents and sea urchins.

26-7 HERNANDEZ, E*; VáZQUEZ, O; TORRUCO, A; RAHMAN, MD; School of Earth, Environmental, and Marine Sciences, University of Texas Rio Grande Valley; *eleazar.hernandez02@utrgv.edu*
Histological evidence of annual and lunar reproductive rhythms of Atlantic sea urchin, Arbacia punctulata in the southern Gulf of Mexico: changes in nutritive phagocytes in relation to gametogenesis
Environmental phenomena such as temperature, photoperiod, tidal cycle and lunar rhythm act as external cues that stimulate the reproductive activity of marine organisms. In this study, we report the annual and lunar reproductive cycles, and changes in nutritive phagocytes (NPs) in relation to gonadal maturation of Atlantic sea urchin (*Arbacia punctulata*, a primeval species). Monthly and weekly changes in gonadal development/maturation were observed histologically. In male, the testicular lobules were densely packed with sperm from June to August. In female, on the other hand, mature eggs first appeared in some ovaries in May, numerically increased from June to July, and decreased in August. During gametogenesis, NPs in both sexes were depleted from June to August. Histological observations revealed that the gonad developed synchronously around the new moon. Collectively, our results suggest that *A. punctulata* spawns several times during the summer months according to lunar cycle in the Gulf of Mexico. This is the first report, to the best of our knowledge, on annual and lunar reproductive rhythms of *Arbacia* species in the Gulf of Mexico, a marginal sea in the Atlantic Ocean surrounded by the North American continent.

8-5 HERNANDEZ, J*; BELDEN, L/K; MOORE, I/T; Virginia Tech; *jess228@vt.edu*
Sexual activity and the cloacal microbiome in female tree swallows
Social behaviors play a role in shaping the diversity and composition of an animal's bacterial communities. Sexual activity, in terms of copulations, is one way through which bacteria can be transmitted socially between individuals. While considerable research has focused on the sexual activity or the microbiomes of animals, little research has focused on the intersection of the two. Here, we experimentally assessed how female sexual activity influences the cloacal microbiome of female tree swallows, *Tachycineta bicolor*. We administered estradiol, ATD (1,4,6-Androstatriene-3,17-dione), and control implants to female tree swallows at the beginning of the breeding season. Manipulation of hormonal activity via estradiol and ATD implants has been well established as an experimental method to increase and decrease sexual activity in female birds, respectively. Then, we assigned parentage of nestlings (a proxy for sexual activity) to determine the minimum number of sexual partners per female. We collected cloacal swabs from experimental females during incubation and subsequently used 16S rRNA gene amplicon sequencing to characterize each females' cloacal microbiome. Additionally, we collected body condition and fitness metrics, such as female mass and reproductive success, to determine if there were negative repercussions of potentially pathogenic cloacal bacteria. This study will broaden our understanding of how sexual activity plays a role in shaping the cloacal microbiomes of wild birds. By understanding how bacterial communities are shaped we can begin to untangle the potential tradeoffs associated with alternative behavioral strategies.

97-1 HERNANDEZ, LP*; OLSEN, AM; BRAINERD, EL; The George Washington University, Brown University; *phernand@gwu.edu*

Convergent means of breaking constraint: How alternative means of premaxillary protrusion have allowed fishes to break functional constraints

Breaking intrinsic developmental constraints can allow for the origin of morphological novelties that overcome functional constraints. Kinethmoid-mediated premaxillary protrusion within cypriniform fishes is one such novelty that breaks some of the morphological constraints seen in acanthomorph-type premaxillary protrusion. Within acanthomorphs significant protrusion requires integrated evolution of the neurocranium to facilitate sliding of a greatly elongated ascending process of the premaxilla, a constraint that is broken by the addition of a kinethmoid to the upper jaw linkage in cypriniforms. This additional linkage allows for increased kinematic flexibility allowing species to more easily feed throughout the water column. Such trophic flexibility also characterizes cyprinodontiform premaxillary protrusion, where the evolution of a novel ligament has allowed for correlated movement of the premaxilla and dentary with no concomitant integration with the neurocranium. Importantly, the impact that different morphological novelties can have on the evolutionary, functional, and ecological history of a specific lineage varies. In the case of kinethmoid-mediated premaxillary protrusion this novelty is associated with ecological diversification; the novelty opens a great number of trophic niches via increased performance. This cypriniform ecological and trophic diversification is also correlated with increased species diversification. Breaking structural constraints may have allowed for increased trophic diversification within these two discrete lineages.

77-1 HERNDON, CJ*; FENTON, FH; Georgia Institute of Technology; *co.herndon@gmail.com*

Corazon espinado: microelectrode closed-loop control in cardiac tissue

Proper contraction of cardiac muscle relies on the coordinated propagation of transmembrane voltage, and disturbances of this propagation can result in deadly cardiac arrhythmias. One such disturbance strongly associated with the onset of fibrillation is a dynamical instability at the cellular level known as alternans, a beat-to-beat alternation in action potential duration (APD). A theoretical model known as the restitution hypothesis describes and predicts alternans via a return map in APD, and decades of work have shown that this model successfully reproduces many experimental observations. Furthermore, the restitution hypothesis likewise predicts a method for suppressing the onset of alternans which has been confirmed by some computational simulations of cardiac cells and tissue; however, few experiments have addressed these predictions due to its difficult implementation. In this talk, I will discuss our development of a closed-loop control scheme to experimentally address the predictions made by the restitution hypothesis via high resolution microelectrode recordings of transmembrane voltages in zebrafish, frog, and rabbit hearts. I will present our results which conclusively show the appearance of alternans in opposition to predictions made by theoretical models and provide an improved model that describes the dynamics.

S9-6 HERREL, A*; ARASPIN, L; PADILLA, P; COURANT, J; SERRA MARTINEZ, A; REBELO, R; IHLOW, F; BACKELJAU, T; MOKHATLA, M; GINAL, P; RöDDER, D; MEASEY, J; CNRS/MNHN, Paris, France, Uuniversity of Lisbon, Portugal, ZFMK, Bonn, Germany, RBINS, Brussels, Belgium, Stellenbosch University, South Africa; *anthony.herrel@mnhn.fr*

Rapid Local Adaptations in an Invasive Frog (Xenopus laevis): the Importance of Functional Trait Measurements to Predict Future Invasions.

The control and eradication of invasive species is an ever-increasing problem for wildlife management and conservation practitioners. Understanding the potential future spread of invasive species is critical to inform management decisions. One often used tool to predict future species distributions is species distribution modelling (SDM) under alternative scenarios of climate change. Although extremely relevant and insightful, most of these models suffer from two drawbacks: 1) the lack of physiological data describing the dependence of organisms on changes in temperature and hydric state; 2) they ignore any potential for adaptive differentiation of invasive populations. To test what the effect could be of these two parameters we focused on invasive populations of the invasive amphibian, *Xenopus laevis*. We collected data on anatomy and physiology (temperature dependence of performance traits) for animals from the source population as well as invasive populations. These data were then used to inform SDMs that predict future spread under different climate change scenarios and to test for the potential adaptive divergence of invasive populations relative to the native population in morphology and physiology. Our results show that incorporating physiological data in SDMs does provide different predictions on future distribution ranges with a much higher invasion potential than previously estimated. Furthermore, our results show rapid (less than 30 years) changes in morphology and physiology in different populations suggesting local adaptation. These results stress the importance of using biologically informed data to inform conservation practices.

50-7 HEWES, A*; SCHWENK, K; University of Connecticut, Storrs; *amanda.hewes@uconn.edu*

A Comparative Study of Lingual Prey Capture in Iguanian and Scincid Lizards

Among lizards, prey are captured with the tongue or the jaws. All iguanians are lingual feeders, and lingual feeding has evolved independently from jaw-feeding ancestors in several other squamate lineages. We compared the functional morphology of lingual feeding in the skink, *Tiliqua scincoides*, with several iguanians using high-speed videography, paraffin histology, and carbohydrate histochemistry. Each prey capture event involves tongue protrusion, tongue-prey contact, and tongue retraction. The proportion of each event devoted to contact and retraction is significantly longer in *Tiliqua* than in iguanians. Tongue-prey contact in *Tiliqua* also involved extensive foretongue spreading, greatly increasing contact area, whereas in iguanians, the contact area is typically minute. Preliminary phylogenetic PCA of tongue histological characters shows that *Tiliqua* groups with jaw-feeding scincid and lacertid taxa, not with iguanians. The iguanian tongue is covered with lingual glands, which are absent on the foretongue of *Tiliqua* and most other skinks. However, the sublingual glands in *Tiliqua* are hugely hypertrophied compared to iguanians and to a lesser extent, jaw-feeding skinks. All taxa secrete neutral mucins, but a preliminary analysis of AB-PAS staining intensity suggests that *Tiliqua* secretes more mucins per unit area than *Sphenodon*, iguanians, and jaw-feeding scincids and lacertids, suggesting greater viscosity and 'stickiness' of *Tiliqua* mucus, a hypothesis we are pursuing with materials testing. All data suggest that *Tiliqua* compensates for a weak adhesive mechanism compared to iguanians by secreting more, stickier mucus, increasing area of contact, and slowing retraction speed to prevent prey loss.

57-1 HEWS, D*; LISIČIĆ, D; GLOGOŠKI, M; BLAŽEVIĆ, SA; HRANILOVIĆ, D; HEWS, Dia; Indiana State Univ, Terre Haute, Univ Zagreb, Faculty of Science, Croatia , Univ Zagreb, Faculty of Science, Croatia; *diana.hews@indstate.edu*

Behavior and Neuroendocrine Differences in Island and Mainland Populations of Wall Lizards (Podarcis sicula): Do They Mirror Typical Within-Population Variation in Stress-Coping Styles?

Alternative reproductive tactics may fit other paradigms that consider behavior differences, including stress-coping styles and personality: consistent individual behavioral differences in multiple contexts or consistent within-individual behavioral correlations. Behavior types often differ in neuroendocrine measures. While many vertebrates show such behavior variation, the ecological contexts favoring these types are less clear. Studying adult males in an island and a mainland population of the Italian Wall Lizard, *Podarcis sicula* , we asked if personality/coping styles typically described for a single population could represent extremes of a continuum, with one personality (less reactive) expressed on the island and the other (more reactive) on the mainland. In the field, we measured either antipredator behavior following a simulated predator approach (flight initiation distance, FID; hiding duration, HD), or breeding-season plasma testosterone (T) and corticosterone (CORT; baseline and 30-min post capture) level in two sets of males, and in the lab we measured behavior and brain monoamines for another set. Island males had lower condition (scaled mass index), shorter HD, lower T, lower aggression, higher open-field activity and lower brain levels of norepinephrine and epinephrine. Novel object exploration, FID, baseline CORT, 30-min CORT, brain dopamine and serotonin did not differ. Future work should examine more populations, and identify selective factors, such as differences in predators and life-history measures, that favor expression of different stress-coping styles in different populations.

40-2 HEYDARI, S*; PO, T; MCHENRY, MJ; KANSO, E; University of Southern California, University of California, Irvine; *sinaheyd@usc.edu*

Sea Star Inspired Crawling and Bouncing

The oral surface of sea stars is lined with arrays tube feet that enable them to achieve highly controlled locomotion on various terrains. The activity of the tube feet is orchestrated by a nerve net that is distributed throughout the body; there is no central brain. How such a decentralized nervous system produces a coordinated locomotion is yet to be understood. We developed mathematical models of the biomechanics of the tube feet and the sea star body. In the model, the feet are coupled mechanically through their structural connection to the sea star body. We formulated hierarchical control laws that capture salient features of the sea star nervous system. Namely, at the tube foot level, the power and recovery strokes follow a state-dependent feedback controller. At the system level, a directionality command is communicated through the ring and radial nerves to all tube feet. We studied the locomotion gaits afforded by this hierarchical control model. We find that these minimally-coupled tube feet coordinate to generate robust forward locomotion, reminiscent of the crawling motion of sea stars, on different terrains and under various heterogeneity in the tube feet parameters and initial conditions. Our model also predicts a transition from crawling to bouncing consistent with our experiments performed on *Protoreaster nodosus*. We conclude by commenting on the implications of these findings for understanding the Echinoderms decentralized nervous system and their potential application to autonomous robotic systems.

36-1 HILL, EC*; JARMAN, MJ; BUTLER, MA; University of Hawaii; *hille7@hawaii.edu*

The Resolution Solution: Increasing Nodal Support in the Problematic Phylogeny for a Large Adaptive Radiation of Papuan Asterophryne Frogs

With over 300 species, the Asterophryinae subfamily is the largest part of the largest amphibian family in the world. Centered in New Guinea and its satellite islands, it forms an adaptive radiation based on microhabitat use. Historically, intergeneric relationships have been difficult to resolve using established morphometric techniques due to phenotypic convergence. However, recent molecular studies have shed light on deeper nodal relationships beginning with Kohler and Gunther (2006) including 40 species, Rivera et al. 2017 including 155 species, and most recently Tu et al. 2018 including 134 species. Unfortunately, many deeper nodes, including the large genus Oreophryne remained unresolved, which may have resulted from rapidly evolving mitochondrial loci that have proven difficult to sequence for all taxa (CYTB, ND4). In addition, some regions of uncertainty within the tree may be due to gaps in geographic sampling. We conducted additional expeditions to Papua New Guinea and collected over 50 new species of Asterophryne from five locations (1 satellite island and 4 mainland sites). We sequenced the loci used in Rivera et al. 2017 (SIA, BDNF, NCX-1, CYTB and ND4), in some cases designed new primers to amplify the fast evolving loci (ND4) for problematic taxa to complete the dataset. Using Bayesian inference as implemented in MrBayes and Bayesian inference + time calibration as implemented in BEAST, we recovered a substantially more resolved phylogeny. We compared the resulting topologies and nodal support to previous phylogenies and investigated the patterns of ecomorph evolution. This analysis will provide a clearer picture of the patterns of early divergence in this particularly fascinating adaptive radiation of microhylid frogs.

S1-10 HINDLE, AG; University of Nevada Las Vegas; *allyson.hindle@unlv.edu*

Diving deep: Mechanistic insights into the extreme physiology of Antarctic seals

Weddell seals are a deep-diving Antarctic species that have been the subject of many seminal studies on diving physiology and behavior. Isolated dive-hole experimental paradigms allowed physiological telemetry and biochemical samples to be collected from unrestrained and freely foraging seals. From these studies, we now recognize the Weddell seal as an elite diver, capable of surviving profound hypoxemia upon submergence, and exhibiting extreme cardiovascular adjustment to distribute limited oxygen stores to key tissues. The mechanisms that define cardiovascular control and provide cell-level protection against hypoxia and subsequent reoxygenation represent the next level in our understanding of the strategies of this extreme breath-hold diver. Neither genetic nor pharmacological manipulations are possible in Antarctic marine mammals, however the availability of a sequenced genome as well as emerging primary cell culture resources provide new avenues to apply modern molecular tools to these questions. Targeted analyses have revealed limited but significant differences in protein coding sequences that can be linked to diving traits such as oxygen storage and vasoregulation. On the other hand, comparative genomic analyses have identified gene regulation as the major signal of evolutionary innovation in the Weddell seal. In particular, differential expression of microRNAs as well as HIF-1a-regulating transcription factors may be important aspects of cardiovascular physiology that enable Weddell seals to dive long and deep.

80-2 HODINKA, BL*; ASHLEY, NT; Simon Fraser University, Western Kentucky University; *brett_hodinka@sfu.ca*
Effect of sleep loss on executive function and baseline corticosterone levels in an arctic-breeding songbird, the Lapland longspur (Calcarius lapponicus)
Sleep is a fundamental and essential component of vertebrate life, although its exact function remains unknown. Animals that are deprived of sleep typically show reduced neurobiological performance, health, and in some cases, survival. However, a number of animals exhibit adaptations that permit them to carry out normal activities even when sleep is restricted or deprived. Lapland longspurs (*Calcarius lapponicus*), arctic-breeding passerine birds, exhibit around-the-clock activity during their short breeding season, with an inactive period of only 3–4 h/day (71°N). Whether these birds suffer behavioral and physiological costs associated with acute sleep loss (SL) is unknown. To assess the effects of SL, wild-caught male longspurs were placed in captivity (12L:12D) and trained for 2 months using a series of memory tests, including color association and spatial learning to assess executive function. Birds were then placed in automated sleep fragmentation cages that utilize a moving wire to force movement every 1 min (60 arousals/h) during 12D (inactive period) or control conditions during 12L (active period). After a single round of SL (or control) treatment, color association and spatial learning tests were conducted. Baseline plasma corticosterone concentration, body mass, and satiety were also assessed. SL significantly elevated corticosterone levels and increased accuracy during the color association test, but not the overall time required to complete the test. SL had no effect upon spatial learning, body mass, or satiety. Taken together, these results suggest that Lapland longspurs exhibit a behavioral, but not a physiological, resilience to acute SL.

54-6 HOLDING, ML*; STRICKLAND, JL; RAUTSAW, RM; MASON, AJ; HOFMANN, EP; HOGAN, MP; COLSTON, TJ; NYSTROM, G; GRAZZIOTIN, F; GIBBS, HL; ROKYTA, DR; PARKINSON, et al., CL; Florida State University, Clemson University, Clemson University, Florida State University, Instituto Butantan, Ohio State University; *matthewholding28@gmail.com*
Comparative analysis of venom complexity and diet diversity in rattlesnakes using a novel, genome-wide phylogeny
Organisms are more than the sum of their parts, making the study of complex integrated phenotypes imperative for understanding the interplay between the evolution of traits and the evolution of species. Molecular trait complexity is particularly important in species interactions, where more diverse networks of species interactions may select for molecular complexity in offensive or defensive traits, such as secreted toxins. Animal venoms, as injected secretions with a tractable genetic basis, are optimal systems for testing the hypothesis that the evolution of more complex molecular traits is associated with interacting with diverse prey taxa. The rattlesnakes (Crotalus and Sistrurus) are the most speciose group of vipers, consisting of ~50 currently described species. We have collected venom glands of 147 individuals snakes, representing most rattlesnake lineages. We use over 1500 nontoxin sequences from venom gland transcriptomes to infer the phylogeny of rattlesnakes, and characterize the composition and complexity of toxin expression in the transcriptomes and in chromatographic profiles of whole venom. We combine a novel, dated phylogeny of rattlesnakes, venom gene expression data, and published diet data to test the hypothesis that more complex venoms evolve in response to a more taxonomically complex diet. Our work provides new insight into the evolutionary history of this complex and iconic group, and relates complexity in patterns of gene expression to the complexity of ecological interactions an organism must face.

S4-9 HOLEKAMP, K. E.*; MONTGOMERY, T. M.; STRAUSS, E. D.; Michigan State University, University of Nebraska; *holekamp@msu.edu*
Social competition and cooperation affect reproductive success of female spotted hyenas
The reproductive biology of many female mammals is affected by their social environment and their interactions with conspecifics. In mammalian societies structured by linear dominance hierarchies, such as that of the spotted hyena (*Crocuta Crocuta*), a female's social rank can have profound effects on both her reproductive success and her longevity. In this species social rank determines priority of access to food, but it also affects females' use of space, energetics, growth, den attendance and social networks. Rank effects appear to be mediated in part by nutrition, prenatal androgen exposure and immune function. Infanticide by higher-ranking females may also function to suppress reproduction in subordinate females. Despite the apparent costs of gregariousness to low-ranking females, gregariousness can also have positive effects on their fitness. These positive effects appear to result from having female allies, both kin and non-kin, who cooperate to advertise and defend a shared territory, acquire and defend food resources, maintain the status quo, and sometimes also to rise in social rank.

104-4 HOLLOWAY, ND*; MACKENZIE, DS; RILEY, BB; Texas A&M University; *nholloway@bio.tamu.edu*
Evidence for expression of the sodium iodide symporter (NIS) in novel neural and ovarian locations in teleost fish
Iodine, an essential component of thyroid hormone, can only be obtained through the diet. The sodium iodide symporter (NIS) transports iodide across mammalian intestinal and thyroid epithelia to deliver iodide for thyroid hormone production. To determine whether a homolog of NIS performs a similar function in teleost fish, we confirmed expression of a homolog of mammalian NIS in both sub-pharyngeal thyroid follicles and intestine in multiple teleost species, indicating a conserved mechanism for intestinal-thyroid iodine transport across vertebrates. We then examined expression in these locations during development using *in situ* hybridization (ISH) staining of zebrafish (*Danio rerio*) embryos. This revealed expression of *nis* as early as 2 days post fertilization (dpf) along the dorsal surface of the yolk sac, suggesting a function to import iodine from yolk, potentially placed there by maternal deposition. To evaluate this possibility, RT-PCR and further *in situ* staining of ovarian tissue in gravid female zebrafish confirmed *nis* mRNA presence in the ooplasm and granulosa layer of early stage follicles. This suggests NIS can function to transport iodine into the yolk, and that maternally-deposited NIS mRNA may be available for early embryogenesis. Additionally, ISH in embryos revealed *nis* expression in the central nervous system throughout days 2-5 dpf, with adult whole brain ISH localizing expression in the hypothalamus, cerebellum, and optic tectum. RT-PCR on whole brain tissue from 5 species of adult fish representing 3 taxonomic orders likewise revealed robust expression. These unexpected, non-canonical locations suggest novel, as yet undescribed reproductive and neural functions of NIS in teleost species.

S10-5 HOLZMAN, R*; OLSSON, K; Tel Aviv University; *holzman@tauex.tau.ac.il*

Using performance landscapes to understand adaptive diversification within fishes

The complex relationship between form and function provides the foundation for the generation of organismal diversity. Selection acts directly on performance, which is the product of interacting phenotypic components. Thus, the ability to predict how multiple phenotypic traits interact in determining performance is key to understanding the evolution of complex functional systems. Here, we demonstrate how performance landscapes, which map the performance consequences of different phenotypic combinations, can be used to understand adaptive evolution of suction feeding fishes. A hydrodynamic model of the suction forces exerted on the prey allows us to explore the complex performance space for aquatic predator-prey interactions, and enables us to predict prey capture performance for any given phenotype. Using this model, we generated performance landscapes for three prey types that pose different challenges to the predators, namely planktonic prey that senses the hydrodynamic disturbance generated by the predator, visually oriented prey that escapes the looming predator and attached prey that clings to its holdfast. We explored the topography of the multidimensional performance landscape and determined it to be rugged with multiple local performance peaks. We used the landscape to generate a-priori hypotheses regarding the position of extant species relative to the theoretical optima in this performance space, which we tested by mapping prey-capture kinematics of fishes from four radiations onto the three generated performance landscapes. Whereas previous research generally focused either on studying phenotypic diversification using morphological traits, or on the biomechanical basis of performance, we integrate these approaches using a detailed mechanistic model to explore how a highly nonlinear and multidimensional performance space shapes organismal diversity in suction feeding fishes.

97-7 HOLZMAN, R*; EYAL, M; MALUL, D; JACOBS, C; Tel Aviv University, Technion; *holzman@tauex.tau.ac.il*

You suck, We suck, Everyone sucks: Homo sapiens display poor suction feeding performance

Hardy's Aquatic Ape Theory proposes that humans evolved to become a two-legged hairless creature via a semi-aquatic diversion that took place around the Pliocene, and that access to marine-based food was a major selective force for this diversion. Among aquatic vertebrates, the most common prey capture strategy is suction feeding. By rapidly expanding the mouth cavity, suction feeders generate a fluid flow outside of their mouth, drawing prey inside. Suction feeding has repeatedly and secondarily evolved in aquatic vertebrates, including marine mammals. However, it is unclear whether humans possess this ability, as could be expected based on their proposed (albeit controversial) history. Using a high-speed flow visualization technique, we characterized the spatio-temporal patterns in the flow fields produced during suction feeding in *Homo sapiens*. We found that mouth opening speed was an order of magnitude slower in *Homo sapiens* compared to fishes. The speed of suction flows was 5x slower than expected based on *H. sapiens* gape diameter (ca 5 cm), and equivalent to that of fish with a gape of about 1cm. Further, flows were not unidirectional; high efflux out of the mouth was observed during mouth closure. Taken together, our results indicate that *H. sapiens* are poor underwater feeders. Adaptations for suction feeding either never existed or have regressed since the Pliocene. Our study therefore failed to provide support for the Aquatic Ape Theory.

138-5 HOOD, KE*; NAVARRO, E; HURLEY, LM; Indiana University, Bloomington, IN; *hoodk@indiana.edu*

Playback of female rejection vocalizations modifies male house mouse (Mus musculus) behavior

Sexual communication is frequently studied from the perspective of male senders signaling to female receivers. However, these interactions are often dynamic with both male and female partners actively sending and receiving signals. Both male and female house mice (*Mus musculus*) signal during sexual interactions. Males primarily produce ultrasonic vocalizations (USVs) that are correlated with investigation and mounting of females, while females primarily produce broadband vocalizations (BBVs) that are correlated with non-vocal rejection behaviors such as kicking and lunging. In order to test the effect of BBVs separately from non-vocal rejection behaviors, male CBA/J mice (n=19) were separated from freely-behaving females with a Plexiglass barrier. In this paradigm, females did not produce any BBVs of their own and males continuously produced high levels of USVs. In response to BBV playback males significantly decreased USV production and increased digging behavior. To identify the role of vocalization structure in the male response males (n=8) were presented with playback of white noise bursts replacing BBVs, which also caused USVs to decrease. Males (n=8) presented with an anesthetized non-behaving female also decreased USV production to BBV playback, although males with anesthetized females produced significantly fewer USVs overall than males with awake females. Overall, these results indicate that males modify their behavior in response to playback of a female signal but this response is strongest in the specific context of an awake female partner. The response may generalize to all broadband noise, including white noise bursts. Response to female BBVs may be used in the future to better understand the mechanisms underlying auditory perception in male mice.

S4-3 HOOK, KA*; FISHER, HS; University of Maryland, College Park; *khook@umd.edu*

The importance of female reproductive traits: from mice to seed beetles

When females mate with more than one male in a reproductive cycle, post-copulatory sexual selection is hypothesized to favor male traits that allow them to outcompete rivals in their race to the egg and female traits that allow them to exercise choice in sperm use. This in turn can lead to conflict between the sexes and a co-evolutionary arms race as they both attempt to optimize their fitness. While it is well understood that these evolutionary processes can critically influence both male and female traits, female traits driven by post-copulatory sexual selection remain relatively understudied. Here I present my research investigating female reproductive traits in both rodents and arthropods. Using a cross-species comparison of six species of mice in the genus *Peromyscus*, we recently characterized the viscosity of the fluid collected from various regions of the female reproductive tract using a combination of optical microscopy and fluorescent nanoparticle tracking. From these data, we assessed the relationship between fluid complexity and mating system and established when and how subtle changes in the microenvironment impacts the collective motion of sperm. My previous work in seed beetles (*Callosobruchus maculatus*) allowed me to establish the pivotal role of female mating behavior in sperm use patterns and sperm competition. My work also suggests that delayed female remating is adaptive for females and is not mediated by sexual conflict driven by male manipulation via components of the ejaculate, as is often assumed. Hinging on male-female and sperm-female interactions, these studies highlight the importance of investigating female traits as well as the co-evolutionary interactions between the sexes for understanding reproductive traits driven by post-copulatory sexual selection.

78-1 HOOVER, AP*; KATIJA, K; The University of Akron, Monterey Bay Aquarium Research Institute; *ahoover1@uakron.edu*
Manse and Tail: Flow structure and morphological constraints of the filtration feeding mechanisms by giant larvaceans
Giant larvaceans (Bathochordaeus) are found throughout the world's midwater region and play an important role in the carbon cycling of these ecosystems. Even though they inhabit the mesopelagic region, larvaceans still manage to be successful filter feeders, with filtration rates of as high as 80 L/hr. This feat is accomplished with the help of a mucus house structure that is built and discarded daily. The house structure allows the larvaceans to direct flows and particles to the filters and mouth of the organism. The flows in the house are driven by the motion of the larvacean tail, which is located at the end of the house filter and oscillates due to a complementary set of muscles on both sides of the tail. This talk will examine this fluid dynamics surrounding this pumping mechanism by using numerical models and experiments to explore the interplay between the tail, the house, and the resulting fluid dynamics that drive this pump. The fully-coupled fluid structure interaction problem is solved using an adaptive and parallelized version of the immersed boundary method (IBAMR).

28-4 HOSSAIN, M*; STAPLES, A; VIRGINIA TECH; *mdmoh81@vt.edu*
Passive Vortical Flows Compensate for Low Flow Speeds in the Interior of a Coral Colony
Metabolic processes like photosynthesis and the transfer of nutrients from the overlying water column to the interior of a coral colony are primarily controlled by the concentration gradients and velocity profiles around the coral. Numerous reef-scale studies have been performed to understand mass transport mechanisms in corals, but smaller scale flow dynamics within branching coral colonies has largely remained unexplored. Measurements have shown that the flow velocities in the interior of densely branched coral colonies can be reduced by up to 90%. In spite of this drastic reduction in flow magnitude, the polyps at the interior of these densely branched corals continue their biological activities normally, pointing to an unknown mechanism for preserving mass transport rates. In this study, we uncovered the mechanism for preserving mass transport rates through a single Pocillopora meandrina colony. We performed three-dimensional simulations of the flow field through the colony (obtained via CT scans of a P. meandrina skeleton) using the immersed boundary method for a realistic Reynolds number of 20,000. The computed flow fields in the interior of the colony are highly vortical because of vortex shedding from the colony's branches, which facilitates mixing and mass transfer. We calculated the advection time scale throughout the interior of the colony in order to characterize the rate of mass transport there. Though average flow speeds were reduced by up to 64% in the interior of the colony, the advection time scale was roughly constant throughout the colony. Thus, the complex, branched geometry of the colony was shown to serve as a passive mass transport enhancement mechanism which compensates almost exactly for drastic velocity reductions in the coral's interior.

24-6 HOUTZ, JL*; SHIPLEY, JR; ZIMMER, C; VITOUSEK, MN; Cornell University, Max Planck Institute of Animal Behavior; *jlh498@cornell.edu*
Impacts of Gut Microbiota on Developmental Temperature Priming in Birds
Early-life challenges, such as suboptimal temperatures during development, can have profound effects on the phenotype. Recent evidence from several mammalian species suggests the gut microbiome may act as a mediator of developmental plasticity, including thermally-induced plasticity. Other recent research has shown that tree swallow (*Tachycineta bicolor*) nestlings developing in suboptimal temperatures have higher stress-induced corticosterone levels and greater thermogenic capacity via enlarged pectoral muscles. Here, we tested the hypothesis that cold-induced phenotypic plasticity is mediated by the gut microbiome. Nestlings were raised at either a cold (31°C) or neutral (35°C) temperature and given an antibiotic cocktail or a water control. Cold-reared birds mounted stronger corticosterone stress responses and higher stress-induced glucose levels than those reared at neutral temperatures. However, antibiotic treatment eliminated both of these effects. Neither temperature nor antibiotic treatment affected baseline corticosterone or glucose levels. Antibiotic treatment increased pectoral muscle mass in cold-reared birds; basal and cold-induced metabolic rates will be analyzed in the future to test whether treatment influenced thermogenic capacity. Thus far, our results demonstrate that gut microbiota may impact cold-induced phenotypic plasticity through alterations of stress responsiveness.

120-5 HOWE, SP*; ASTLEY, HC; University of Akron; *sph43@zips.uakron.edu*
Bio-inspired Control Algorithms Integrating Steady Swimming and Maneuvering in Fish Robots
The majority of fish use whole-body undulations to power swimming and generate maneuvers. This style of locomotion offers certain benefits including efficiency and stealth, and consequently fish are excellent models for designing autonomous under water vehicles (AUVs). While straight swimming can be generated by simple cyclical motions, unsteady behaviors such as turning are more complex. Previous control strategies for maneuvering in fish robots fall into two major categories. The first adds a lateral offset to the normal locomotor wave, biasing the undulation to the right or the left without interrupting normal swimming. The second imitates the C-start maneuver in fish, in which all body segments deflect simultaneously on one side followed by a rapid, posteriorly propagating straightening, which interrupts typical locomotor body oscillations. We developed a turning model based on the kinematics of routine maneuvers from the Giant Danio (*Devario aquepinnatus*), which consist of pulses of curvature that start near mid-body and propagate posteriorly. These pulses are non-cyclic events and can be modeled as a transient wave with a speed, amplitude, and width. Using a 3D printed robot, we will be evaluating the performance of the pulse model compared to the offset wave and C-start methods. We have also successfully implemented the pulse, the C-start, and offset control models in a multilink robotic system. Preliminary data shows that the pulse model behaves similarly to the live fish model. All three models are able to execute maneuvers, but further testing will show how the maneuverability, agility, and controllability compare between the turn models.

31-4 HOWE-KERR, LI*; BACHELOT, B; WRIGHT, RM; KENKEL, CD; BAY, LK; CORREA, AMS; Rice University, Smith College, University of Southern California, Australian Institute of Marine Science; *lih2@rice.edu*

Symbiont diversity correlates with variability in holobiont stress tolerance

Coral reefs are experiencing global declines as climate change and other stressors cause environmental conditions to exceed the physiological tolerances of host organisms and their microbial symbionts (collectively termed the holobiont). To assess the role of symbiont community composition in holobiont stress tolerance, diversity metrics and abundances of dinoflagellate endosymbionts were quantified from eight *Acropora millepora* coral colonies (genets) that thrived under or responded poorly to various stressors. Four best performer coral genets were selected for analysis because they survived 10 days of high temperature, high pCO2, bacterial addition, or combined stressors, whereas four worst performer genets were analyzed because they experienced significant mortality under these stressors. Seven of eight genets mainly hosted *Cladocopium* symbionts, but also contained *Symbiodinium, Brevolium,* and/or *Durusdinium* symbionts at lower abundances. Control fragments of each genet ultimately identified as best performing had low symbiont alpha and beta diversity, whereas the worst genets had higher alpha and beta diversity. After 10 days of stress, symbiont communities in worst performers had a greater proportional increase in symbiont variability (relative to control fragments) than did the best performers, with bacteria and heat treatments causing the most drastic changes in symbiont communities. These findings emphasize that community diversity metrics may be important indicators of resilience in hosts central to diverse disciplines, from agriculture to medicine.

82-1 HOWEY, CAF; University of Scranton, Scranton, PA, 18510 and Pennsylvania State University, University Park, PA 16802; *christopher.howey@scranton.edu*

Thermoregulation and Foraging Behavior of Timber Rattlesnakes (Crotalus horridus) in a Disturbed Landscape

Prescribed fire is a landscape disturbance that alters the physical and thermal characteristics of a habitat. Changes to the thermal landscape may benefit ectothermic organisms as they are able to maintain elevated body temperatures that may coincide with preferred body temperatures. However, changes to the physical characteristics of a burnt landscape may affect other ecological aspects including risk of predation and foraging efficiency. It was the objective of this project to determine if prescribed fire affected the thermal landscape and thermoregulatory behaviors of an ectothermic species, the timber rattlesnake (*Crotalus horridus*), and to determine if physical changes to the habitat affected the behaviors of this organism. I radio-tracked *C. horridus* for two years before and two years after a prescribed fire in central Pennsylvania. I recorded behaviors, movement rates, home range sizes, and body temperatures of each snake throughout the project. Biophysical models were placed in burnt and unburnt treatments each year to measure operative temperatures. I found that burnt landscapes provided warmer operative temperatures. Radio-tracked *C. horridus* also maintained warmer body temperatures when occupying burnt habitat. However, foraging behaviors were solely restricted to unburnt habitat. Trapping efforts suggest no change in small mammal abundance in burnt and unburnt landscapes. Rather, data from a concurrent scent-trailing study suggest that *C. horridus* may not be able to detect chemical stimuli on burnt substrate. Thus, even though small mammals were present in the burnt treatment, *C. horridus* may not have been able to detect suitable ambush sites.

136-1 HU, Y*; HARPER, M; DONAHUE, J; ACOSTA, B; MCMENAMIN, S; Boston College; *hucy@bc.edu*

Thyroid Hormone Mediates Proximal-Distal Patterning in Zebrafish Fin Skeleton

Caudal fin morphology varies extensively among fish species, yet we know very little about the developmental programs underlying such diversity. Further, the molecular pathways that create proximal versus distal morphological characteristics in the fins are poorly understood. In zebrafish, the caudal fin skeleton is composed of bony fin rays made up of individual segments, which taper and shorten distally, and form a primary branch at about half of the fin's length at adult stage. Mutations in various ion channels are known to cause overall scaling of the entire fin, but the morphological features along the proximal-distal axis are maintained in proportion. In contrast to these proportionally scaled changes, we identify a novel role for thyroid hormone in patterning the proximo-distal morphology of the fin rays. While thyroid hormone is a well-known endocrine regulator of skeletal development and is generally considered to promote bone mineralization, the role as a proximo-distal patterning factor is novel. We show that the hormone mediates both the proximo-distal morphology of the ray segments as well as the position of the fin ray branches, but not overall fin size. Thus, thyroid hormone acts independently of the bioelectricity-mediated pathways that regulate fin growth. Sonic hedgehog signaling is known to be essential in fin ray branching, and we show that thyroid hormone acts upstream of this pathway. Further, our expression analyses show differences in the transcriptomes of proximal versus distal regions of the regenerating fin, suggesting target pathways that create proximal versus distal morphologies; our data are consistent with thyroid hormone regulation of these proximo-distal expression patterns. In all, our results provide new insights into the mechanisms underlying proximo-distal identity as well as adaptations in the fin skeleton.

139-5 HUBICKI, CM*; DALEY, MA; Florida State University, University of California, Irvine; *chubicki@fsu.edu*

Optimal control predictions of running behavior in cursorial birds: non-rigid terrain, scaling, and maneuvering

Many species of bipedal runners, such as cursorial birds, can run at a variety of speeds. However, each species has a pattern for choosing gait features⁄ (e.g. stride length - SL, stride frequency - SF, and duty factor - DF)⁄ for achieving any selected speed. This work uses theoretical math models combined with optimal control methods to predict these gait features across speeds by minimizing energy cost. Specifically, this work compares a spring-legged math model with swing costs against the experimental gaits of helmeted guinea fowl (*Numida meleagris*) during steady running across speeds. A three-parameter fit (spring stiffness, damping constant, and leg inertia) generated steady gaits on rigid terrain from 1.3m/s to 3.1 m/s with SL, SF, and DF similar to measured guinea fowl data - all as a consequence of energy minimization. These parameters are fitted once for the species, and are constant across speeds and terrain conditions. Further, modeling the terrain as a dissipative surface (e.g. sand or soft soil) predicts an increased DF, consistent with experimental data. We are currently testing the broader ability for the model to predict gait features of species with varied leg length and inertia relative to body mass (e.g. red-legged seriema (*Cariama cristata*) and elegant crested tinamou (*Eudromia elegans*)). Preliminary analysis suggests that birds with larger leg inertia prolong their flight phases as the model predicts. In ongoing work, we are applying this modeling framework to multi-step manuevers, such as a 90-degree turns, to test scenarios that require higher-level decision-making.

53-4 HUDSON, SB*; VIRGIN, EV; SMITH, GD; BRODIE JR., ED; FRENCH, SS; Utah State University, Dixie State University; *spencer.hudson@usu.edu*

Energetic strategy, oxidative cost, and performance outcome vary according to magnitude of an integrative immune challenge

The central tenet of life-history theory posits allocation to fitness-related traits reduces the amount of available resources that can be invested into competing traits, resulting in trade-offs. Immunity and whole-organism performance capacity fit within the life-history framework as physiologically costly traits crucial for survival. Life-history trade-offs may occur when the demands of immune traits impinge upon investment in performance traits, and vice versa. Whether shifts in performance capacity occur under such conditions was determined in side-blotched lizards (Uta stansburiana) through comparisons of maximal sprint speed and rates of healing from wounds (i.e., cutaneous biopsies) of various sizes. Energy budget (i.e., food intake) and oxidative stress (i.e., pro-oxidants versus antioxidants) associated with immune and performance investment were also compared among lizards by wound size. Findings herein reveal sprint speeds are not constrained when healing from wounds of increasing sizes. Instead, healing and sprint speed deviate with wound size such that both are concurrently invested when healing from small wounds, at a trade-off for medium wounds, and variably invested for large wounds. Such findings indicate performance expression adjusts according to the demands of an immune challenge, perhaps to offset the energetic and oxidative costs of immunological prioritization. However, energy intake decreases and oxidative stress increases with greater wound size, suggesting components of self-maintenance or long-term survival may become compromised if an immune challenge exceeds a certain magnitude.

129-4 HUIE, JM*; THACKER, C; TORNABENE, L; University of Washington, Natural History Museum of Los Angeles County; *jmhuie@uw.edu*

Co-evolution of cleaning and feeding morphology in Caribbean and eastern Pacific gobies

Cleaning symbioses are mutualistic relationships where cleaners remove and consume ectoparasites from their clients. Cleaning behavior is rare in fishes and is a highly specialized feeding strategy only observed in around 200 species. Cleaner fishes vary in their degree of specialization, ranging from species that clean as juveniles or facultatively as adults, to nearly obligate or dedicated cleaners. Here we investigate whether these different levels of trophic specialization correspond with similar changes in feeding morphology. Specifically, we model the evolution of cleaning behavior across the family Gobiidae, which contains the most successful radiation of dedicated and facultative cleaner fishes. We compared the cranial morphology and dentition of cleaners and non-cleaners across the phylogeny of cleaning gobies and found that facultative cleaners independently evolved three times and have converged on an intermediate morphology relative to that of dedicated cleaners and non-cleaning generalists. This is consistent with their more flexible feeding habits. Cleaner gobies also possess a distinct scraping tooth morphology, which suggests they are adapted for scraping parasites off their clients and show little similarity to other cleaner clades. We propose that evolutionary history and pre-adaptation underlie the morphological and ecological diversification of cleaner fishes.

46-6 HULETT, RE*; POTTER, D; LUO, YJ; RICCI, L; SRIVASTAVA, M; Harvard University; *rhulett@g.harvard.edu*

Identifying regulators of neural cell-type diversity during regeneration in the acoel Hofstenia miamia

The nervous system is extremely complex, composed of many cell-types creating intricate circuits responsible for coordinating action. Adding to the previously known diversity of cell-types in the nervous system, single-cell RNA sequencing (scRNAseq) in select organisms has uncovered tremendous heterogeneity in neural cell-types. Within these adult organisms, few are capable of regenerating diverse neural cell-types and even fewer are able to regenerate their entire nervous system. Acoel worms represent a major phyletic lineage capable of robust regeneration and include the new research organism, *Hofstenia miamia*. *Hofstenia* is capable of whole-body regeneration, i.e. it has the ability to replace any missing cell-type, via differentiation of its adult pluripotent stem cells, called neoblasts. *Hofstenia* has an organized nervous system and can regenerate all missing neural cells-types and structures, and we sought to identify the molecular/genetic regulators governing the transition from neoblast to differentiated neural cell-type during regeneration. Utilizing scRNAseq data, we identified putative neural populations and subpopulations, which we validated using fluorescent in situ hybridization and immunohistochemistry. Within each major neural population, we recovered candidate transcription factors that we hypothesize to govern differentiation of neural populations during regeneration. We are utilizing systemic RNAi to determine the functions of these transcription factors during regeneration with regards to the replacement of diverse neural cell-types. This work will reveal mechanisms for neural regeneration as well as provide a comparative framework to understand the evolution of these mechanisms.

S3-1 HULSEY, CD; University of Konstanz, Germany; *darrin.hulsey@uni-konstanz.de*

The evolutionary developmental genetics of vertebrate tooth size

Tooth sizes vary extensively across vertebrates. Substantial amounts of this variation can be attributed to isometric scaling with changes in organismal body size, but there are a number of additional factors that influence diversification of tooth sizes. Trophic specializations such as crushing hard-shelled prey or piercing provide clear functional bases for predicting changes in tooth size components such as the width and length of teeth. However, teeth are also used for a large vareity of non-trophic organismal functions that could influence tooth size and these will be discussed as potential mechanisms of tooth size diversification. The developmental genetic mechanisms governing tooth size are likely to be equally diverse, and I will highlight recent insights into the mechanistic basis of vertebrate tooth size divergence gleaned from transcriptomics and comparative genomics of cichlid fishes.

104-2 HUNT, KE*; BUCK, CL; HUDSON, J; FERNáNDEZ-AJó, A; HEIDE-JøRGENSEN, MP; FERGUSON, SH; MATTHEWS, CJD; George Mason U, N Arizona U, U Manitoba, Greenland Inst Nat Res, Fish Oc Canada; *kehunt@gmu.edu*

Patterns in Reproductive Seasonality Inferred From Annual Testosterone Cycles In Baleen Of Adult Male Bowhead Whales (Balaena mysticetus)

Whale baleen accumulates steroid hormones as it grows, such that a single baleen plate can be used to reconstruct an individual's endocrine history over the timespan of baleen growth, 1-2 decades in bowhead whales (*Balaena mysticetus*). We analyzed testosterone (T) and corticosterone (B) in baleen of nine adult males from eastern Canada and Greenland to infer breeding season and frequency, and associated adrenal activity. Baleen plates of 184-314 cm length were drilled at 2 cm intervals (each interval representing ~1-2 mo), followed by assay of immunoreactive T and B. T concentrations cycled along baleen of all nine males. Average T periods ranged from 21 cm in the smallest whales to 14 cm in the largest whales, consistent with annual bowhead baleen growth rates and differential growth rate associated with age (slower in older individuals). Change in T peak amplitude over time was significantly related to whale body length (a proxy of age), suggesting influences of sexual immaturity, reproductive competition, and possible reproductive senescence. Annual T peaks were strongly correlated with stable nitrogen isotope (15N) peaks in summer but with an offset of several months, indicating elevated T concentrations during spring, the purported breeding season. B concentrations cycled synchronously with T in some males, while variation was irregular in others, consistent with known bowhead whale breeding behavior (i.e. likely differences in reproductive competitiveness). We conclude that male bowheads experience annual testosterone cycles, and that baleen hormone analysis enables investigation of reproductive seasonality in whales.

S2-12 HUNTER, R/G; University of Massachusetts Boston; *richard.hunter@umb.edu*

Transposons, Stress and the Endocrinology of the Deep Genome

Transposons have played a significant role in the evolution of eukaryotic genomes, and exaptation of transposons has led to innovations such as the mammalian placenta and the adaptive immune system. Since McClintock's discovery of what she called "controlling elements," it has been evident that they tend to mobilize in response to stresses to the organism. This observation raises two questions: how does the genome control the stress-induced expression of transposons? Moreover, how do transposons detect stress? Much of the epigenetic machinery has been evolved to suppress or control these elements, and our work has shown the mammalian brain uses some of the same mechanisms of transposon control as have been observed in other organisms. We have shown that stress rapidly induces an increase in the repressive histone H3 lys9 trimethyl mark in the rat hippocampus. Further, corticosteroids themselves, acting via the glucocorticoid receptor (GR) act to increase the expression of B2 SINE and IAP-LTR retrotransposons, offering an answer to the question of how transposons detect organismal stress. Further, we have observed a potentially novel mechanism by which transposon derived RNA might serve to block GR action, leading to glucocorticoid resistance at the genomic level. Our observations that transposon expression varies substantially across sex suggest that sex steroids may also interact with these elements. There is abundant evidence that transposons and steroid receptors have been involved in an ancient interplay across vertebrate evolution. Roughly a third of the GR targets in the rat hippocampus are within or near transposons, and many steroid response elements in gene promoters are transposon derived. This data argues that, beyond their established role in genome evolution, transposons play day to day role in normal endocrine physiology.

44-5 HUYNH, AH*; RICE, AM; Lehigh University; *avh210@lehigh.edu*

Chemical communication in a hybridizing chickadee system: olfaction and reproductive isolation

Understanding how mating cues promote reproductive isolation upon secondary contact is important in describing the speciation process in animals. Divergent chemical cues have been shown to act in reproductive isolation across many animal taxa. However, such cues have been overlooked in avian speciation, particularly in passerines, in favor of more traditional signals such as song and plumage. Here we show evidence for odor as a mate choice cue, potentially contributing to premating reproductive isolation in a chickadee hybrid zone. Using gas chromatography-mass spectrometry, we document significant species differences in uropygial gland oil chemistry between the black-capped (Poecile atricapillus) and Carolina chickadee (P. carolinensis). We also demonstrate significant preferences for conspecific over heterospecific odor cues in wild chickadees using a Y-maze design. Our results suggest that odor may be an overlooked but important mating cue in these chickadees, potentially promoting premating reproductive isolation. In addition, we also show evidence for a loss of odor preferences in adult hybrids. This loss of behavioral response may be coincident with other cognitive deficiencies previously found in hybrid chickadees, and may contribute to the stability of the hybrid zone via postzygotic reproductive isolation.

110-3 INGLE, DN*; PORTER, ME; Florida Atlantic University, Boca Raton, FL; *dingle2014@fau.edu*

Cetacean vertebral trabecular bone mechanical properties and structure vary among swimming modes and diving behaviors

Among cetaceans, species with rigid, torpedo-shaped bodies are considered as the fastest and most active swimmers. Interspecific variation is encoded in the axial skeleton, where vertebral morphology varies among species with different locomotion modes. Here, we categorized 10 species of cetaceans (Families Delphinidae and Kogiidae) into functional groups determined by swimming modes (rigid vs. flexible body) and diving behavior (shallow vs. deep). We quantified trabecular bone mechanical properties and structure among cetacean functional groups and regions of the vertebral column. We hypothesized that trabecular bone would be stronger, stiffer, and thicker in shallow-diving, rigid-bodied swimmers and in the caudal vertebral column. Vertebrae were obtained from necropsies and dissected from four regions of the vertebral column (thoracic, lumbar, and two caudal). Vertebrae were μCT scanned in a Bruker SkyScan 1173, and trabecular thickness was quantified. After scanning, 6mm3 bone cubes were sawed from vertebrae and compression-tested at 2 mm/min using an Instron E1000 material tester. Yield strength and toughness were calculated using stress-strain curves. Rigid-bodied, shallow-diving cetaceans had the strongest, toughest, and thickest trabecular bone in the caudal region of the vertebral column, and had the greatest values of all functional groups. Conversely, flexible deep-divers showed no regional variation in trabecular mechanical properties and structure and had overall less strong, tough, and stiff bone. These data suggest that in addition to whole body rigidity, animals that habitually overcome surface drag and wave turbulence have increased skeletal loading during active swimming than those that incorporate prolonged glides during deep descents in the water column.

128-5 ISON, T*; CHARBONNEAU, D; WAUGH, A; LINKSVAYER, T; DORNHAUS, A; University of Arizona, Tucson, Arizona State University, Phoenix, University of Pennsylvania, Philadelphia, University of Pennsylvania, Philadelphia; *tjison@email.arizona.edu*

The Effects of Aging: Task Allocation and Inactivity in Two Ant Species

Eusocial insects and other colonial organizations are considered to be some of the most effective and intricate social establishments in the natural world. In particular, insect colonies are thought to employ efficient and dynamic task allocation mechanisms matching workers to tasks needing work. Worker age is typically related to the tasks they perform where younger workers tend to perform safe tasks (e.g. nursing) closer to the center of the nest where they first emerge into adults and transition to outward and riskier tasks (e.g. foraging) over the course of their lives; this idea of temporal polyethism has been demonstrated in honey bees and is thought to apply in some degree to most social insect species. Here we examine temporal polyethism in two ant species with very different life histories – the long lived and slow paced Temnothorax rugutalusand the fast paced with a short worker lifespan Monomorium pharaonis by tracking the behavior of workers through their aging process. Our data will show how age relates to individual inactivity (known to vary consistently among individuals) as well as the type of task performed in each life stage. Both study species have shown evidence of high inactivity levels in younger workers, however the inactivity-age relationship in T. rugutalus is more complex than that of the M. pharaonis. This may be because of the long lifespan of T. rugutalus where older workers may senesce versus short-lived workers who may die before their physiologies degrade. Studying the role of age in task allocation among widely different species, as well as the relationship between inactivity and age, offers insight into the stability and adaptive task allocation in dynamic environments.

14-4 JACOBS, C*; DAY, S; HOLZMAN, R; Tel Aviv University, Rochester Institute of Technology; *corrinej2@gmail.com*

A power amplification dyad in Syngnathidae

Suction feeding is the most common prey capture strategy across teleosts. However, the intensity of the suction flow is constrained by the fish's ability to produce fast movements as muscles contract slowly and over small distances. During rapid movements, tendons can act like springs, temporarily storing work done by muscles and then releasing it to power body movements. This is known as power amplification and the only known example in fish, is pivot feeding in the Syngnathidae family, whose members are able to rotate their snout towards the prey at exceptionally high speeds of ~20000°s-1. While the mechanism of power amplification that permits these exceptional speeds is well documented, the consequences of power amplification for suction feeding are poorly understood. Using a high-speed flow visualization technique, we characterized the spatio-temporal patterns in the flow fields produced during pivot feeding in 3 species of the Syngnathidae family. We discovered that due to power amplification, the Syngnathidae were able to create 8x greater flow velocities than similar-sized fish without this mechanism. The measurements from the flow fields were used to estimate the pressure fields in front of the mouth and calculate net suction power (power used to accelerate the water outside of the mouth). The power used for suction feeding was found to closely match the available power within the tendon of the sternohyoideus muscle, suggesting dyad power amplified system. This allows for the rapid head rotation buy the epaxial tendon and 8x greater flow velocities, compared to fish with no such mechanism, from the sternohyoideus muscle tendon. As far as we are aware, this is the first documented duel power amplified biomechanical system used for separate functions simultaneously!

S5-9 JAFFAR-BANDJEE, M; STEINMANN, T; KRIJNEN, G; CASAS, J*; University of Tours, CNRS, University of Twente; *casas@univ-tours.fr*

Efficiency of odor capture by multiscale pectinate insect antennae

While the pectinate antennae of silk moths and other insect groups are considered as the paragon of sensitivity to sexual pheromones since centuries, we still lack a mechanistic understanding of odor capture by such structures. 3D printing cannot currently fabricate multiscale structures spanning the antennal four orders of magnitude. We therefore focus on the functional, two-scales sub-structure of an antenna of Samia cynthia (Lepidoptera, Saturniidae): a brush of sensory filliform sensilla attached to one rami, the supporting tubular structure. A semi-analytical model to compute mass transfer, originally developed for heat transfer in pipes, is adapted to the specific geometry of longitudinal sensilla facing the flow. Particle Image velocimetry (PIV) is used with scaled-up physical models for estimating the leakiness of the structure, i.e. the proportion of flow passing through the structure rather than around. The combination of these experimental and modeling approaches delivers the capture efficiency over a biologically relevant range of air speed. We found that two distinct processes are setting pheromone capture efficiency. At low Re numbers, leakiness at the higher organizational scale, i.e. the entire substructure, determines the efficiency of odor capture. At higher Re numbers, advection at the lower organizational scale of a single sensillum is determining efficiency. We study how this trade-off results into capture efficiency of the entire sub-structure and observe that the multiscale architecture of the pectinate antenna of insects is highly adapted for odor capture over a large range of flow speeds. We end by discussing the embedding of this sub-structure in an entire antenna, using cylinders as proxy for the sub-structures. Their diameter is determined such that the cylinders have the same drag as the sub-structures.

29-8 JAN, I*; SANGHA, G; SCHULZ, JR; Occidental College; *tjan@oxy.edu*

The Cone Snail Strikes Back: A Biomechanical Study of an Ultrafast Prey Capture

While predatory cone snails have been extensively studied for their venom properties, their ultrafast prey capture mechanism remains relatively recondite. The fish-hunting *Conus catus* of the family Conidae hydraulically propels a hollow radular harpoon that tethers and injects venom into prey. In this biomechanical study, we studied the priming step, prey strike, and venom delivery of the prey capture. Energy is stored as the radular harpoon is forced against a unique cellular latch within the proboscis, a distensible appendage, until adequate pressure exceeds the latch mechanism. Subsequently, the radular harpoon reaches high accelerations—achieving velocities that mark this prey strike as the fastest in mollusks and one of the fastest in animals—before even more rapidly decelerating as the bulbous base travels to the end of the proboscis. We observed fast venom delivery following such high-speed prey strike, as the velocities of ejected venom dramatically dissipate prior to or during proboscis withdrawal. To determine if similar mechanisms exist in other members of the Conoidea superfamily, we studied *Hastula hectica* of the closely related Terebridae family to identify analogous structures critical to the ultrafast prey capture of *C. catus*. Consequently, this system may be found in a large subset of diverse marine gastropods beyond just cone snails.

122-4 JANKAUSKI, MA; Montana State University; *mark.jankauski@montana.edu*

On the Nonlinear Mechanics of the Honeybee Thorax

The thorax (or thorax-wing assembly) of flying insects is widely believed to behave as a resonant mechanical oscillator. Thorax resonance is likely critical to the function of asynchronous muscles and may reduce the energetic costs of flight. Some orders of insects, such as Diptera or Hymenoptera, modulate their wingbeat frequencies during flight to affect aerodynamic force production. This implies that, if the thorax indeed behaves as a resonant oscillator, it must behave nonlinearly – linear oscillators have fixed resonant properties. To address potential nonlinearity, we performed a series of experiments on freshly sacrificed Honeybee *Apis mellifera* thoraxes. First, we conducted static force-displacement tests on the thorax about its ventral axis. Over the approximate range of in-vivo displacements, we found the thorax behaved approximately as a nonlinear hardening spring that became stiffer as it was compressed. Next, we mounted the thorax on a custom vibration shaker system in order to identify the thorax's linear resonant frequency as a function of compression. From zero to maximum compression, the thorax resonant frequency increased by as much as 100 Hz. This is consistent with the static force-displacement testing, since the thorax linear natural frequency is theoretically proportional to its stiffness. Our results suggest that insects may adjust the equilibrium state of their thorax in order to modulate wingbeat frequency.

67-4 JARMAN , MJ *; HILL, EC; BUTLER , MA; University of Hawaii, Honolulu ; *mjarman@hawaii.edu*

When You Need a Miracle: Amplifying and Sequencing Degraded DNA Through Touchdown and Nested PCR Techniques.

There are many situations where investigators are faced with degraded DNA samples, but still need to obtain sequence data. This can include the analysis of ancient DNA, museum specimens, and even fresh tissues that have been delayed in transit and allowed to decompose. Particularly when samples are rare or prohibitively expensive to replace, it can be important to maximize data obtained from limited and damaged material. Two major problems are low template concentration and fragmented template. We explored the efficacy of touchdown and nested PCR strategies, without the use of special reagents, to recover sequences under less than ideal situations. We found that when DNA quantities are very low, it is difficult to amplify and visualize the data. We used the touchdown PCR technique to minimize the use of template DNA and avoid temperature optimization for each primer/template combination. Theoretically, PCR can work with a single strand of template, however, starting with very low concentration typically does not yield enough product to obtain reliable sequence information. We used the nested PCR technique, adding a second set of primers that are designed to sit internally to the original primer set. We were able to use the PCR product from the initial touchdown PCR as template for the nested PCR, yielding high concentrations of amplified DNA to visualize on agarose gels and Sanger sequence. Using combinations of these techniques we were able to obtain sequences of up to 600 base pairs for phylogenetic study, even in samples with little high molecular weight template (too low to visualize on an agarose gel). These methods may be applicable to many situations where template is degraded and in low quantity.

S6-6 JAWORSKI, JW; Lehigh University, Bethlehem, PA; *jaworski@lehigh.edu*

Acoustic models for wing specializations of silent owl species

Many owls species are known to be able to hunt in effective stealth to themselves and their prey, a feat which is attributed in full or in part to their wing specializations. Two of these specializations, the trailing-edge fringe and the velvety pennula on the upper-wing surface, are investigated using mathematical models with the goal to establish a physics-based understanding of their associated noise generation. These models take into account the porous and/or elastic nature of these owl wing features to examine their ability to potentially disrupt standard routes of noise production in low-speed flows. An emphasis is placed on the relevance of noise results to the range of sizes of owl species, with accompanying morphological measurements where appropriate. The technological impact and applications of noise-reduction technologies inspired by owl plumage will also be described.

S8-3 JAYNE, BC; University of Cincinnati; *jaynebc@ucmail.uc.edu*

What Defines Different Modes of Snake Locomotion?

Animals move in diverse ways, as indicated in part by the wide variety of gaits and modes that have been described for vertebrate locomotion. "Gaits" and "modes of locomotion" both refer to any repeatable pattern of movement of the propulsive structures. Much variation in the gaits of limbed animals is associated with changing speed, whereas different modes of snake locomotion are often associated with moving on different surfaces. For several decades different types of snake locomotion have been categorized as one of four major modes: rectilinear, lateral undulation, sidewinding and concertina. Herein, I highlight some of my work from the last three decades that suggests such a scheme may be overly conservative. For example, during aquatic lateral undulation the timing between muscle activity and lateral bending changes along the length of the snakes, which is unlike terrestrial lateral undulation. Lateral undulation at the edge of a surface while bridging a gap also uses a different motor pattern than lateral undulation on a horizontal surface that supports the entire length of the snake. In all types of concertina locomotion, the distance from the head to the tail changes substantially as snakes alternately flex and then extend different portions of their body. However, snakes climbing with concertina exert forces medially to attain a purchase on the branch, whereas tunnels require pushing laterally to form an anchoring region. Furthermore, different motor patterns are used for these two types of concertina movement. Some snakes climb vertical cylinders with helical wrapping completely around the cylinder, whereas all other forms of concertina bend regions of the body alternately to the left and right. Regardless of the taxonomy that is ultimately favored for categorizing modes of snake locomotion, it should be one that does not obscure important functional differences.

91-1 JIAO, Y*; COLVERT, B; MAN, Y; MCHENRY, M; KANSO, E; University of Southern California, University of California, San Diego, University of California, Irvine; *jiaoyush@usc.edu*
Evaluating Evasion Strategies in Zebrafish Larvae
Predation is a primal interaction between species, yet it is unclear what evasion strategies are effective for prey survival. Existing theories suggest that the prey should escape in an optimal direction that maximizes its distance from the predator or in a random and therefore unpredictable direction. Here, we propose several evasion models of zebrafish larvae, including the distance-optimal and random strategies. We built probabilistic models that account for sensory and response noise and used statistical methods to assess these models in comparison to experimental data. This novel approach allowed us to evaluate the relative merits of multiple evasion strategies in predicting the behavior of prey. We found that two strategies are best supported by experimental observations: the distance-optimal strategy and a simpler strategy where prey fish swim orthogonally to the predator's heading. The orthogonal strategy is a special case of the distance-optimal strategy in the limit of fast predators, yet it requires less sensory effort. We argue that the orthogonal strategy is optimal when considering the neuro-sensory circuits underlying evasion. To probe these circuits, we developed a biomechanical model of the fast response of larval zebrafish that addresses the physical constraints on the motor control of evasion. Taken together, these results suggest that fish adopt a strategy that saves both the perception complexity and the physical difficulty in motor actuation.

38-2 JIMENEZ, YE*; BRAINERD, EL; Brown University; *yordano_jimenez@brown.edu*
Regionalized contributions of the epaxial musculature to swimming and suction feeding in bluegill sunfish
Many fishes can recruit the axial musculature for both swimming and suction feeding, yet little is known about how this dual-function muscle operates under the distinct mechanical demands of these behaviors (lateral versus dorsal axial flexion). Using electromyography and sonomicrometry, we measured muscle activity and strain for suction feeding and burst swimming in three dorsoventral epaxial regions in a bluegill sunfish. Sunfish consistently activated the dorsalmost epaxial region for low- and high-performance strikes and added activation of the middle and ventral regions for high-performance strikes on live prey. By contrast, sunfish always activated all three epaxial regions for fast-starts. Our results suggest that sunfish use recruitment patterns similar to largemouth bass, where they increase performance for suction feeding by activating the epaxial muscle from dorsal to ventral, and in the case of swimming, from ventral to dorsal. We also found that longitudinal strain varied with respect to distance from the vertebral column, as predicted by beam theory. Strains for fast-starts were highest in the lateral region and lowest in the medial region, while strains for suction feeding were highest in the dorsal region and lowest in the ventral region for suction feeding. Our EMG data suggest that sunfish vary regional muscle recruitment for modifying swimming and suction feeding performance. Our strain data suggest that the different modes of axial bending used for feeding and swimming behaviors create distinct strain gradients. Future studies examining the relationship between longitudinal strain and muscle fiber strain are needed to quantify regional differences in power output for swimming and suction feeding.

80-5 JIMENO, B*; LANDRY, D; STAGER, M; WOLF, C; PRICHARD, M; CHEVIRON, Z; BREUNER, C; University of Montana; *bjimenorev@gmail.com*
Metabolic traits, but not corticosterone concentrations, are associated with reproductive investment in tree swallows
Organisms continuously face environmental fluctuations, and allocation of metabolic investment to meet changing energetic demands is of fundamental importance to survival and reproductive success. Glucocorticoid (GC) hormones (e.g. corticosterone –CORT-) play an important role in energy balance and acquisition on the face of environmental challenges, by mediating metabolic processes involved in energy metabolism. Although fluctuations in GCs and metabolic rate are expected to covary, surprisingly few empirical studies have demonstrated relationships between GC concentrations and metabolic rate in wild, free ranging animals. We measured CORT (baseline and stress-induced) and metabolic traits (resting metabolic rate –RMR-, cold-induced VO2max, and aerobic scope) in female tree swallows (*Tachycineta bicolor*) during chick-rearing, and tested for their associations with several variables of reproductive performance. We found that only metabolic traits were associated with reproductive success; females with higher reproductive output showed higher resting metabolic rate and lower VO2max. Moreover, we found a positive relationship between resting metabolic rate and baseline CORT, but other associations between metabolic rates and CORT levels were not significant. This suggests that while baseline CORT may be a good indicator of an individual´s baseline metabolic investment, stress-induced CORT may be more stimulus-specific, and does not reflect aerobic scope or the upper limits of aerobic performance. Overall, our results suggest that metabolic traits may be better predictors of reproductive investment in tree swallows than CORT parameters. They further suggest the available energy budget may be more constrained in females investing more heavily in a current reproductive event due to elevated baseline metabolic costs.

S3-8 JOHANSON, Z*; UNDERWOOD, C; MANZANARES, E; FERNANDEZ, V; CLARK, B; SMITH, M; Natural History Museum, London, UK, Birkeck, University of London, UK, Universitat de Valencia, Spain, King's College, London, UK; *z.johanson@nhm.ac.uk*
Evolution of the Dentition in Sharks
Sharks and their relatives belong to the major vertebrate group, Chondrichthyes, with an evolutionary history that extends back over 450 million years. Recent research has focused on an improved understanding of the phylogenetic relationships of chondrichthyans, in particular stem-group relatives of the crown groups Elasmobranchii (sharks and rays) and Holocephali (chimaeroids). Knowledge of these relationships is crucial to understanding how chondrichthyan teeth, within a patterned dentition, have evolved in the elasmobranchs, including in new model taxa such as the catshark *Scyliorhinus* and the Little Skate *Leucoraja*. Development of the dentition in the elasmobranchs, and particularly in sharks like *Scyliorhinus*, is becoming increasingly well understood, including genes involved in tooth regeneration and rotatory successive replacement. Rays like the Little Skate show very similar processes with respect to tooth addition, as new teeth are iteratively added to sets across the jaw. In an evolutionary sense, teeth arranged into files on the jaw first appear in stem chondrichthyans known as acanthodians (420-250 million years ago), with this character, rotatory succession, retained in stem relatives of the elasmobranchs and holocephalans, representing the primitive condition for sharks and rays. However, the holocephalans are particularly notable, with extant representatives (crown group holocephalans) characterized by dentitions lacking teeth, lost during the evolution of the group; neither tooth germs, nor successive teeth have been observed in embryos or adults. Exactly when, and how, these teeth were lost, compared to the elasmobranchs is an area of research ripe for exploration.

32-1 JOHN, JS*; THOMETZ, NM; BOERNER, K; DENUM, L; KENDALL, TL; RICHTER, BP; GASPARD, JC; WILLIAMS, TM; University of California Santa Cruz, San Francisco University, San Francisco, CA , Mote Marine Laboratory & Aquarium, Sarasota, FL, Mote Marine Laboratory & Aquarium, Sarasota, FL, Pittsburgh Zoo & PPG Aquarium, Pittsburgh, PA; *jsjohn@ucsc.edu*

Energetics of swimming in tropical marine mammals- Examining metabolic tradeoffs in West Indian manatees and Hawaiian monk seals

One of the most challenging aspects of the marine environment for mammals is thermoregulation due to the high heat transfer rate of water. Despite this there are few marine mammal species found exclusively in tropical regions and little is known about the energetic consequences of warm water adaptations on locomotor costs in these species. Working with Hawaiian monk seals (*Neomonachus schauinslandi*) and West Indian manatees (*Trichechus manatus*) as our model tropical species, we used flow-through respirometry to measure resting metabolic rate (RMR), stroke cost (SC), and cost of transport (COT) in 2 adult manatees at Mote Marine Lab (Sarasota, FL) and 1 adult monk seal at Long Marine Lab (Santa Cruz, CA). We found low average RMRs for both the monk seal (748.7 $kJ \cdot hr^{-1}$) and manatees (885.9 $kJ \cdot hr^{-1}$) relative to other marine mammals. In contrast, SC and COT were in line with predicted marine mammal values for both the monk seal (SC = 5.1 $J \cdot kg^{-1} \cdot stroke^{-1}$, COT = 1.7 $J \cdot kg^{-1} \cdot m^{-1}$) and manatees (SC = 2.6 $J \cdot kg^{-1} \cdot stroke^{-1}$, COT = 1.0 $J \cdot kg^{-1} \cdot m^{-1}$). This dichotomy indicates that thermoregulatory costs strongly influence RMR, but that costs associated with locomotion are more strongly affected by hydrodynamic interactions. While allometric analyses have proven useful in predicting energetic costs for many marine mammal species, the divergent thermoregulatory and hydrodynamic factors highlighted here for tropical species need to be accounted for when modeling energetic costs across tropical, temperate, and polar species.

70-2 JOHNSEN, S*; CAVES, EM; Duke Univ., Exeter Univ.; *sjohnsen@duke.edu*

How our perceptual and cognitive biases may influence our study of animal vision

It has long been appreciated (and celebrated) that certain species have sensory capabilities that humans do not share, for example ultraviolet vision and magnetoreception. What is less appreciated however, is that our position as terrestrial human scientists can significantly affect our study of animal senses and signals, even within modalities that we do share. For example, our acute vision can lead us to over-interpret the relevance of fine patterns in animals with coarser vision, and our Cartesian heritage as scientists can lead us to divide sensory modalities into orthogonal parameters (e.g. hue and brightness for color vision, angle and degree for polarization vision), even though this division may not exist within the animal itself. In addition, we often use lab-based assays to make ecological predictions, even though the sensory environment is completely different. Finally, we may assume that what is salient and striking to us must be so to other animals. This talk examines two cases from marine visual ecology where a reconsideration of our biases as sharp-eyed Cartesian land mammals can help address questions in visual ecology. The first case examines the enormous variation in visual acuity among animals with image-forming eyes, and focuses on how acknowledging the typically poorer resolving power of animals can help us interpret the function of color patterns in cleaner shrimp and their client fish. The other case examines the how the typical division of polarized light stimuli into angle and degree of polarization is problematic, and how a Stokes vector interpretation is both closer to the physiological truth and resolves a number of issues, particularly when considering the propagation of polarized light underwater and whether polarization vision can be used to break camouflage.

103-1 JOHNSON, TL*; DEFINO, NJ; RAUSCHER, MJ; HECKSCHER, ES; FOX, JL; Case Western Reserve University, University of Arizona, University of Chicago; *jlf88@case.edu*

Interneurons for Mechanosensory Processing in Adult Drosophila

Sensory-motor integration is important for coordinating behaviors like walking and flying. In the larvae of *Drosophila melanogaster* , neurons expressing the gene Even-skipped receive mechanosensory and proprioceptive input, and are necessary for coordinating muscle contractions. When these neurons are ablated by expression of the apoptotic transgene Reaper, larval crawling becomes uncoordinated. The function of these neurons is unknown in adults, but anatomical evidence suggests that Even-skipped neurons receive input from the halteres, the flies' gyroscopic reduced hindwings. We hypothesized that Even-skipped neurons receive critical sensory input from halteres, which help transmit signals to the wings and head to function properly. To test this hypothesis, we compared the behavior of intact wild-type flies, flies with mechanically ablated halteres, and flies expressing Reaper in the Even-skipped neurons. We tested adult flies performing three different behaviors: free take-off, tethered flight, and tethered flight with imposed body rotations. We observed body position, wing amplitudes, and head positions during these behaviors. Flies expressing Reaper in the Even-skipped neurons behaved similarly to flies with mechanically-ablated halteres, and both of these groups performed significantly differently from wild-type flies. These behavioral results are consistent with the hypothesis that Even-skipped neurons provide essential sensory input via the halteres.

98-8 JOHNSON, KM*; SIROVY, KA; KELLY, MW; Louisiana State University, Baton Rouge; *kmjohnson@lsu.edu*

VARIATION IN DNA METHYLATION AND GENE EXPRESSION BETWEEN AND WITHIN FAMILIES OF THE EASTERN OYSTER Crassostrea virginica

Populations of eastern oysters (*Crassostrea virginica*) in the Northern Gulf of Mexico will be challenged by predicted changes in environmental conditions associated with climate change. As environmental variation shifts, a combination of phenotypic plasticity and local adaptation will be important mechanisms that may allow one population to outperform another within a given estuary. Recent evidence suggests that there are population specific patterns in DNA methylation in *C. virginica* and that DNA methylation is significantly affected by changes in the environment. In this study we have explored changes in DNA methylation and gene expression between 2 populations of *C. virginica* collected from a high and a low salinity site along coastal Louisiana. Crosses within each population were conducted at Grand Isle Hatchery (LA) and the progeny were out-planted at either a medium-high salinity site (Grand Isle, LA; 21 psu) or at a low-salinity site (Chauvin, LA; 9 psu). To test for the effects of rearing environment and genotype we sampled 20 oysters for each population from each site after 1 year. We assessed changes in DNA methylation using reduced representation bisulfite sequencing (RRBS) and changes in gene expression using 3'TAG-sequencing. With this approach it was possible to genotype each individual in order to disentangle genetic from environmental drivers of both DNA methylation and transcriptome level plasticity. This analysis identified some variation in methylation and expression between families within a site - suggesting a genetic basis for the variation; and highlighted that the majority of plasticity was observed between common garden out-plant sites but within the low salinity population.

21-7 JOHNSON, MW*; TRICOMO, AS; SHOUGH, AE; SANDERS, JC; COHEN, SC; San Francisco State University, Humboldt State University, University of Portland, Southern Illinois University Edwardsville; *mjohnson18@mail.sfsu.edu*

Investigating the Foraging Behavior of Leptasterias spp. Across Intertidal Microhabitats

The coastal intertidal zone contains much fine-scale habitat variation, related to a variety of abiotic factors including wave exposure. *Leptasterias* spp. is a genus of predatory sea stars found along the west coast of North America, and across intertidal microhabitats with varying levels of exposure to wave stress. *Leptasterias* spp. are limited dispersers - embryos are brooded, which may lead to differentiation or local adaptation. Preliminary data suggests behavioral differences among stars from different microhabitats that may reflect differential adaptation to prey accessibility and stressors associated with low and high wave exposure. We investigated the foraging activity of *Leptasterias* spp. from sites with inferred high and low wave exposure in central and northern California. Prior to collection, we estimated field prey availability by quantifying abundance in 50 cm^2 quadrats surrounding individual stars. Crawl distance and prey choice were then tested in static seawater tanks and in a two-current flume tank. High and low wave-exposed sites showed different prey composition, and stars from low wave-exposed sites crawled farther than high wave-exposed stars (Mann Whitney U = 173.5, p = 0.038). Although *Leptasterias* spp. showed an overall tendency to detect and choose prey in a two-current flume tank (One-sample proportion test, p = 0.053), prey choice did not differ between stars of different microhabitats. *Leptasterias* spp. may use chemoreception in foraging, and the extent to which other behavioral differences reflect microhabitat and clade may vary.

92-6 JONES, BC*; DUVAL, EH; Florida State University; *jonesbc@gmail.com*

Development of the glucocorticoid stress response and its effects on growth in a tropical passerine

The dampened hormonal stress responses in neonates is thought to be an adaptive response against the damaging effects of exposure to chronically high concentrations of glucocorticoids, such as retarded growth. Glucocorticoids facilitate the mobilization of stored energy but can also promote anabolic processes in specific contexts. Understanding the development of the glucocorticoid stress response and when and how glucocorticoids affect growth are important for predicting how growing animals will respond to perturbations. We investigated the development of the hormonal stress response and the relationship between endogenous corticosterone (Cort) and growth in the lance-tailed manakin (Chiroxiphia lanceolata). We subjected 11-day-old nestlings and adult manakins to a standardized capture and restraint protocol to measure baseline and stress-induced levels of Cort post-capture. We found that nestlings had an attenuated stress-response and faster negative feedback compared to adults. We also compared concentrations of Cort to mass and skeletal growth. Baseline concentrations had an inverted U-shaped relationship with both mass and structural growth. Stress-induced concentrations had a negative relationship with structural growth but did not affect mass. These results demonstrate the importance of validating the timing of stress series protocols in developing young independent of those used for adults. Further, Cort appears to facilitate growth at low concentrations, while overall mass is buffered against the negative effects of high concentrations of Cort at the expense of structural growth. This is likely important for altricial avian species, as they rely on fast structural growth, particularly of wings, to minimize predation risk in the nest.

112-4 JONES, CLC*; HUBER, RJ; KIM, W; PRATER, C; SHAFER, ABA; WAGNER, ND; FROST, PC; Enivronmental and Life Sciences Graduate Program, Trent University, ON, Department of Biology, Trent University, ON, Department of Biology, Trent University, Peterborough, ON, Department of Geography, Loughborough University, UK, Department of Forensic Science, Trent University, ON, Center for Reservoir and Aquatic Systems Research, Baylor University,TX; *catrionajones@trentu.ca*

Animal co-limitation by calcium and phosphorus revealed through experimental nutrigenomics

Lakes across the Canadian Precambrian Shield and northern Europe are experiencing declines in ambient phosphorus (P) and calcium (Ca) at unprecedented rates. While these declines may create or exacerbate nutrient-stress in aquatic food webs, our ability to detect and quantify nutrient-stress of these two elements on zooplankton remains limited. Here, we use next generation RNA sequencing technology and differential gene expression analysis to examine the molecular phenotypes produced by single and combined limitation of these two key dietary nutrients in the freshwater zooplankter, *Daphnia pulex*. Our results reveal an intermediate phenotype in Ca- and P-stressed animals, which provides evidence that *D. pulex* experiences nutritional co-limitation by both nutrients. We used transcriptome data to identify the most highly up- and down-regulated metabolic pathways, which are presumably involved in mitigating the physiological effects of poor P- and Ca-nutrition. These data provide us with the necessary groundwork to begin unravelling complex multi-nutrient interactions in nature and allow us to start making predictions about the effects of multiple declining nutrients on populations and communities. We believe that nutrigenomics has the potential to address many of the inherent complexities in studying nutritional interactions. Further work is needed however to lay the genomic groundwork necessary to carry out this type of analysis on non-model organisms (i.e. genome sequenced and annotated, gene ontogeny predictions, etc).

5-3 JORGE, J*; PATEK, SN; Duke University; *jfj7@duke.edu*

Taking a swing at measuring small-scale, high acceleration impacts: a novel two-pendulum approach

Impact dynamics underlie many biological motions including prey capture and locomotion. Oftentimes, the size and time scale of these impacts allow for measurement with force transducers, strain gauges, or accelerometers. However, motions like the ultrafast mandible strikes of a trap jaw ant occur at incredibly small scales placing them outside the range of traditional sensors. Furthermore, these strikes have many uses (from prey capture to mandible powered jumps) against diverse biotic and abiotic materials. When measuring these strikes, we must consider the material properties of the struck target, whether or not the target is fixed, and the contact duration. Here we measure energy transfer from a trap jaw ant into a target with a novel two-pendulum device. The device consists of two separate pendulums with an ant affixed to the end of one pendulum and a target affixed to the end of another. We tested impacts on two target materials: spring steel and polyurethane. We hypothesized that impacts on spring steel would yield higher energy outputs than the more compliant polyurethane. Each target material was tested by positioning the ant close to either a freely-swinging target or a fixed target to provoke a strike. Our data supported the hypothesis that, due to differences in energy absorption, impacts with polyurethane yield lower average energy of pendulum motion (6.3 µJ) than with spring steel (22 µJ). Fixing the targets did not significantly affect measured energy. Contact duration was a key predictor of energy across all treatments. Longer contact durations led to lower measured energy, which is a fundamentally different dynamic of these small impact systems compared to larger jumping animals that maximize ground contact time to enhance energy exchange during impact.

42-4 JUAREZ, BH*; MOEN, DS; ADAMS, DC; Iowa State University, Oklahoma State University; *bryanhjuarez@gmail.com*
Morphology Predicts Interspecific Jumping Performance in Frogs
Ecological and evolutionary processes depend on individual fitness. Oftentimes, organismal performance is a more accurate predictor of individual fitness than morphology. Recent work has shown that organismal performance, such as feeding performance in fishes, can sometimes be estimated from morphology. Here we test whether morphological proxies can predict jumping performance across 167 individuals from 29 species of frogs. First, we used biological and physical principles to mathematically derive three anatomical proxies for three aspects of jumping performance: jumping velocity, energy, and power. These anatomical proxies use non-invasive anatomical measurements such as the hip length, leg length, body size, and mass of frogs to estimate jumping performance. Second, we used phylogenetically generalized least squares and ordinary least squares regression to assess the precision with which these anatomical proxies allow us to predict jumping performance across the morphological, ecological, and geographical diversity represented in our interspecific dataset. Preliminary analyses indicate that we are reasonably able to estimate all three aspects of jumping performance. The ability to predict jumping performance from morphology (e.g. using museum specimens) allows the rapid sampling of many individuals. Therefore, relative to traditional laboratory methods, this new method enables us to more easily collect the large sample sizes necessary to test different macroevolutionary-level hypotheses regarding the jumping performance of anurans, and possibly other jumping animals.

5-4 JUNG, SJ*; KIM, S; WU, B; DOMBROSKIE, J; Cornell University; *sj737@cornell.edu*
Shattering raindrops on biological surfaces (insect wings, bird feathers)
Many biological surfaces (e.g. bird feathers, insect wings, and plant leaves) are super-hydrophobic with physical morphology at different scales. However, it is not well understood how a raindrop impacts natural super-hydrophobic surfaces, and its significance of biological functions. In this present study, we found that a spreading drop at a high speed can generate wrinkled pattern (including shock-like waves) on a spreading liquid in the presence of surface morphology at the micro scale. Furthermore, the spreading drop is suddenly ruptured by growing holes followed by the shock waves, which leads to a decrease in contact time more than 50%. As a result, heat and momentum transfers are reduced by raindrops, which may lower the hypothermia risk of animals or less affect the stability of insect flights. Additionally, we revealed that the drop fragmentation sheds smaller satellite droplets, which play a crucial role in promoting wet pathogenic dispersal by carrying pathogenic spores along. Therefore, our results shed light on multi-functional aspects of biological super-hydrophobic surfaces.

114-1 JURESTOVSKY, DJ*; USHER, L; ASTLEY, HC; University of Akron; *djj64@zips.uakron.edu*
Propulsion via vertical undulation in snakes
Snakes have multiple modes of locomotion including lateral undulation, concertina, rectilinear, and sidewinding. During lateral undulation, snakes generate posteriorly-propagating waves of body bending which press against irregularities in the environment and generate propulsive reaction forces. We hypothesize that snakes are capable of using the same mechanism in the vertical plane, using vertical waves of body deflection to generate propulsion from vertical substrate irregularities. We used six corn snakes (*P. guttatus*) to test this hypothesis using an array of horizontal cylinders oriented perpendicular to the direction of travel, one of which was instrumented to record forces. Surrounding this setup are motion capture cameras recording at 120 fps and a GoPro camera to track the snake's kinematics and to confirm that the snake is crossing the cylinders with minimal horizontal bending (and thus not generating propulsion via lateral undulation). Results show snakes produce both propulsion and braking across the pegs, with various trials showing pure propulsion, pure braking, or a combination of both. The magnitudes of peak propulsive force and braking are 0.0586 body weights (BW) (0.043 - 0.075 BW) and 0.0590 BW (0.039 - 0.077 BW), respectively. In contrast, when an inert rope approximately the same weight as the snakes was dragged across the force sensor, it produced only braking force. While this experimental setup was designed to elicit locomotion solely via vertical undulation in order to demonstrate the mechanism most clearly, it is likely that in complex, three-dimensional natural terrain, snakes can combine both lateral and vertical undulation for maximal locomotor efficacy.

129-3 JUSTYN, NM*; HEINE, KB; PETEYA, JA; HOOD, WR; SHAWKEY, MD; WANG, B; HILL, GE; Auburn University, John Carroll University, Ghent University; *nmj0005@tigermail.auburn.edu*
Persistence of Carotenoids in the Red Eyespots of Copepods (Tigriopus californicus) on Carotenoid-free Diets
Copepods can serve as a model for investigations into the functions of carotenoids in animals. Previous work on *Tigriopus californicus* demonstrated that copepods rely on their diet to accumulate carotenoids in their bodies and suggested that, despite their red color, eyespots contained no carotenoids. When fed a carotenoid-free diet of yeast, the orange coloration of the bodies of copepods fades away while the eyespot remains a bright red color. The eyespots of copepods play an important role in many behaviors including diel vertical migration, food acquisition, and predator detection. Elucidating the mechanism behind the source and maintenance of eyespot color in copepods is therefore crucial to understanding these behaviors. Here we used Raman spectroscopy to detect the pigments present in copepods fed both normal and carotenoid-free diets. We detected the red carotenoid, astaxanthin, in *T. californicus* eyespots of both diet groups, as well as in the eggs and the cuticles of normal red-colored individuals. Additionally, we also identified canthaxanthin for the first time in the antennae and caudal rami of normal and diet-restricted individuals, as well as in the bodies of diet-restricted individuals. We will discuss the implications of the persistence of carotenoids in the eyespot even with no access to dietary carotenoids.

114-2 KABA, AK*; RIESER, JM; PAEZ, VM; ASTLEY, HC; GOLDMAN, DI; Georgia Tech, Akron University; *abdul.kaba1@gmail.com*

Amplitude Modulation in Sidewinding Locomotion Driven by Contact Sensing Facilitates Movement in Heterogeneous Environments

As sidewinders move, only some portions of the snake are in contact with the ground at any time. This changing contact pattern can be modeled as vertical wave coupled to the lateral wave. The result is a sideways motion that causes a broad animal profile along the direction of movement and potentially makes obstacle negotiation more difficult than other modes of undulatory locomotion. Biological experiments revealed that the sidewinder is able to squeeze its body, which we hypothesize is achieved by increasing the amplitude of the horizontal wave, to move past rigidly-anchored vertical posts placed in their path. To test our hypothesis, we created a sidewinding robot from 14 alternating horizontally-and vertically-actuated servo motors connected with 3D printed brackets. The horizontal motors commanded a sinusoidally-varying lateral wave and the sinusoidally-driven vertical motors created a changing contact pattern. We implemented a controller and contact sensing capabilities on our robot, the robot responds to contact by increasing its horizontal amplitude for one full cycle. We positioned the robot at the same initial condition relative to the post for 30 trials each with and without the controller. Without control, the robot was always unsuccessful as its tail end gets caught and the robot spins around the post. With the controller, the robot was able to pull its tail end towards its head to successfully squeeze past 80% of the trials.

28-1 KACZMAREK, EB*; LI, EY; BRAINERD, EL; Brown University; *elskabette@gmail.com*

XROMM Analysis of Air-Breathing in the Royal Knifefish, Chitala blanci

Approximately 50 families of fishes contain species that are known to breathe air. The ability to breathe air, in addition to ventilate their gills with water, allows these species to survive in oxygen-poor habitats. While the behaviors and anatomical structures used to breathe air are diverse, numerous species possess a respiratory gas bladder and use buccal pumping to ventilate it. It is likely that buccal pumping was used by the first air-breathing fishes and by the tetrapodomorphs that transitioned to living on land, which makes it an evolutionarily interesting behavior. The kinematics of this method of air breathing have been previously described from 2D x-ray videos of a handful of fish species. Here we present the first 3D kinematics of air-breathing in the royal knifefish, *Chitala blanci*, a facultative air-breather that uses four-stroke buccal pumping. We used X-ray Reconstruction of Moving Morphology (XROMM) to measure cranial bone motions and muscle shortening. As air is released from the gas bladder, the suspensoria abduct and the cleithra retract, depressing the hyoid bars. The buccal cavity then compresses to expel the stale air through the opercular valves. Opercular elevation depresses the lower jaw via the interoperculomandibular ligament, and the cleithra retract by 5 to 10 degrees, causing the hyoid bars to depress by up to 40 degrees to draw in fresh air. The sternohyoideus does not shorten during hyoid depression. Knifefish also rely on large amounts of lateral expansion to widen their laterally-compressed heads—the suspensoria abduct as much as 10 degrees, and the two halves of the lower jaw spread 20 degrees apart from each other, as do the left and right hyoid bars. Comparing the air-breathing kinematics among species may shed light on the evolutionary history of this important behavior.

14-3 KAHANE-RAPPORT, SR*; SAVOCA, MS; CADE, DE; SEGRE, PS; BIERLICH, KC; CALAMBOKIDIS, J; FRIEDLAENDER, AS; JOHNSTON, DW; WERTH, AJ; GOLDBOGEN, JA; Stanford University , Duke University, Cascadia Research Collective , University of California, Santa Cruz , Hampden-Sydney College ; *skahaner@stanford.edu*

From Feast Mode to Least Mode: How Lunge Filter Feeding Biomechanics Constrain Rorqual Foraging Ecology Across Scale

Large body size is widely recognized to confer many benefits, including reduced transport costs and enhanced diving capacity. Such advantages should allow divers to increase their ability to forage at depth, increasing overall foraging efficiency. Rorqual whales engulf a large mass of prey-laden water at high speed and filter it through baleen plates retaining prey. This lunge feeding mechanism incurs a large energetic cost due to high drag, but provides the animal with extraordinary prey consumption rates. However, as engulfment capacity increases with body length across species (Engulfment=length$^{3.2}$*10$^{0.61}$,r^2=0.96), the surface area of the baleen filter does not increase proportionally (Baleen area=length$^{1.85}$*10$^{0.18}$,r^2=0.83).Therefore, we hypothesize that these scaling differences lead to longer filtration time (Filter time length$^{1.5}$) for rorquals of larger body size because the baleen surface area filters a disproportionally large amount of water. We tested this hypothesis on 4 rorqual species using 40 cetacean-mounted video and 3D accelerometry tag deployments with corresponding drone photogrammetry that provided direct measures of body size, lunge rates, and filtration times. Our findings show that filter time increased with body length (Filter time=length$^{1.8}$*10$^{-0.6}$, r^2= 0.86), whereas the number of lunges per dive decreased with size (Lunges per dive =length$^{-0.8}$*10$^{1.7}$, r^2=0.55). Although larger rorqual whales should have increased diving capacity, the disproportional cost and filter time required to engulf larger volumes progressively limits dive time that could otherwise be spent selecting the highest quality prey patches.

26-5 KAHN, AS*; PENNELLY, CW; LEYS, SP; Moss Landing Marine Laboratories, Moss Landing, CA, University of Alberta, Edmonton, Canada; *akahn@mlml.calstate.edu*

Factors Affecting the Behaviors of Sessile Animals on the Deep Seafloor

Deep-sea communities are linked with processes occurring at the ocean's surface despite their relative distance apart. Time-series observations have highlighted the responses of benthic animals to episodic pulses of food and rhythmic changes in surface climate; however, in most of these cases observations have been made on mobile fauna. How and whether sessile animals on the abyssal plain can also respond behaviorally to changes in surface climate has largely been ignored. We combed through 30 years of time-lapse camera data from Station M, a long-term study site on the abyssal plain off the coast of California, to survey behaviors and activity of sponges and benthic cnidarians. The sessile fauna of the abyssal plain initially appear static but time-lapse observations yield a new, long-term perspective showing the dynamic lifestyles of these animals. Several hexactinellid sponge species rhythmically contracted and expanded back to full size, a process taking days to weeks that coincides with a reduction in filter feeding by one-third to nearly one-half. In general, cnidarian behaviors were at shorter timescales, occurring more frequently and with less time spent contracted than sponges. Zoanthids had rhythmic contraction behaviors whereas the cerianthid anemone *Bathyphellia australis* retracted its body into its tube with no apparent pattern or periodicity. These observations expand on the natural history of these difficult-to-observe taxa. Furthermore, the behaviors of these sponges and cnidarians may affect their role in nutrient cycling.

115-6 KAMRAN, M*; POLLOCK, AMM; DITTMAN, A H; NOAKES, DLG; Oregon State University, Corvallis, Northwest Fisheries Science Center, National Marine Fisheries Service, NOAA, Seattle, Oregon State University, Corvallis and Oregon Hatchery Research Center, Alsea ; *kamran.mary@gmail.com*

Homeward Bound: What the Salmon Nose Knows?

Aquatic habitats tend to be highly complex sensory environments with little to no light but are oftentimes rich in terms of dissolved compounds. Reliance on chemoreception can be particularly advantageous in these environments as chemical cues provide animals information about their surroundings. For aquatic species, olfactory cues play a critical role in mediating a range of behaviors such as kin recognition, avoidance of predators and homing. Pacific salmon exhibit natal homing, where adults return to their natal tributaries in freshwater to spawn. These migrations are remarkable in terms of both the spatial and temporal scales over which these movements occur, with adults travelling thousands of kilometers to their natal tributaries after a period of several years at sea. We know that imprinting of odors occurs at critical developmental periods and this may be the mechanism through which juveniles learn odors associated with their home streams. While salmon are able to detect several classes of compounds, odors that serve as olfactory cues during navigation remain unidentified. We conducted a series of behavioral choice assays using juveniles to evaluate the effectiveness of candidate odorants for imprinting within hatcheries. By improving olfactory imprinting and homing success of hatchery fish, we may be able to minimize interactions between hatchery and wild salmonid populations.

97-6 KANE, EA*; HIGHAM, TE; Georgia Southern University , UC Riverside; *ekane@georgiasouthern.edu*

Apparent modulation of integration with prey type in bluegill is driven by individual differences in performance and its integration

Integration refers to the ability for parts of an organism to work together, often to accomplish a higher-level function. Parts can be defined as covarying performance traits, where integration helps organisms achieve ecologically relevant tasks. Since performance is behavioral, traits or their integration may be able to respond to changing ecological contexts on short time scales, such as capturing alternative prey types. In suction-feeding fishes, integration between approach (locomotor) and capture (feeding) kinematics is broadly supported, but performance in each of these functional systems can also be modulated based on prey evasiveness. Therefore, we ask how modulation of component performance traits to capture evasive and non-evasive prey types affects their integration in bluegill sunfish. As expected, bluegill modulated between relatively slow swimming/high suction force to capture non-evasive prey, and fast swimming/high suction volume to capture evasive prey. Using multivariate partial least squares ordination followed by general linear model regression analyses, we found that reduced integration with evasive prey, likely a factor of gape limitation at fast swim speeds, was driven by individual specialization for relatively evasive/non-integrated and non-evasive/integrated capture strategies, not by flexibility of integration within individuals. Whether specialized performance drives integration, integration constrains the flexibility of performance, or any of these traits may be learned is unclear. Despite this, these results suggest that performance integration is a whole-organism phenotype and selection on integration (if present) acts on individuals rather than behaviors.

S8-12 KANO, T.*; ISHIGURO, A.; Research Institute of Electrical Communication, Tohoku University; *tkano@riec.tohoku.ac.jp*

Decoding Decentralized Control Mechanism Underlying Adaptive and Versatile Locomotion of Snakes

Snakes have lost their limbs and acquired the ability to move in various environments by using a simple one-dimensional body structure through long-term evolutionary process. Specifically, snakes have various locomotion patterns and change them in response to the environment. For example, on an unstructured terrain, snakes actively utilize terrain irregularities and move effectively by actively pushing their bodies against "scaffolds" that they encounter. In a narrow aisle, snakes exhibit concertina locomotion in which the tail part of the body is first pulled forward with the head part anchored, and this is followed by the extension of the head part with the tail part anchored. This ability has attracted attention to roboticists and many snake-like robots have been developed thus far. Most of these robotic studies aim for engineering applications such as search-and-rescue operation, yet our approach is different: our standpoint is "robotics-inspired biology" rather than "bio-inspired robotics". Namely, we are motivated to understand the decentralized control mechanism underlying adaptive and versatile locomotion of snakes by developing robots. In the presentation, we will introduce our results for these ten years.

39-7 KANWAL, J.K*; DE BIVORT, B.L; SAMUEL, A; Harvard University; *jkanwal@fas.harvard.edu*

Early integration of multisensory information in the Drosophila larva

The brain integrates information from different sensory modalities in order to enhance detection and perception of external stimuli and to respond in the most efficient manner. For a *Drosophila* larva, this means detecting chemosensory cues to locate the most nutritious food source in its environment. How the larva integrates olfactory and gustatory cues, at both the neuronal and behavioral levels, remains largely unknown. To assess the larva's behavioral strategy for chemosensory integration, we compared its navigation behavior on attractive olfactory or gustatory gradients alone to that on simultaneous presentations of both gradients in parallel or in conflict. Larvae show multisensory enhancement in their navigation efficiency towards the most attractive region of their chemosensory environment when both gradients are in parallel compared to either one alone. Placing the two gradients in conflict reveals that neither sensory system gates the other. Using in vivo calcium imaging to record neural activity, we identified several local and projection neurons within the antennal lobe, the first olfactory processing center in the larval brain, that respond to both odors and tastes or are modulated by odor-taste mixtures. To our knowledge, these results indicate for the first time that neurons in the antennal lobe have multisensory responses. Our findings support the idea that multisensory integration occurs at early stages of sensory processing and begin to address how this convergence enhances perception and shapes foraging behavior.

S4-7 KARACHIWALLA, Z; DECARVALHO, T; BURNS, M*; Department of Biological Sciences, University of Maryland, Baltimore County, Keith R. Porter Imaging Facility and Department of Biological Sciences, University of Maryland, Baltimore County; *burnsm@umbc.edu*

Spermathecal Variation By Mating System in Temperate Harvestmen

As in mammals, most arachnid fertilization occurs internally, allowing for a variety of post-copulatory mechanisms to take place. Females are expected to exert some level of control over sperm fate when 1) the the point of fertilization is particularly distant from the point of oogenesis, 2) the time of fertilization is occurs significantly later than the time of mating, 3) sperm are non-motile, and/or 4) the morphology of females allows for selective containment of sperm. Many of these conditions are met in Opiliones. Fluorescent microscopy of spermathecae from Opiliones of the suborder Eupnoi has revealed a variety of morphologies that may have critical function in controlling seminal movement, and we have evidence of polygynandrous mating and delayed oviposition in a number of species. Preliminary data on spermathecal morphology in temperate genera *Hadrobunus* and *Leiobunum* has deviated from initial expectations that more complex spermatheca would be found in species with conflict-based mating systems, as females of some species with high sexual antagonism have relatively simplistic spermatheca, while females of some species with low antagonism have multi-chambered organs with apparent valvular openings. These findings will have significant implications for the study of reproductive mode maintenance in facultatively parthenogenetic species that may use spermathecal mechanisms to withhold or bias paternity.

S3-6 KARAGIC, N*; MEYER, A; HULSEY, CD; University of Konstanz, Konstanz, Germany; *nidal.karagic@uni-konstanz.de*

Plasticity of Vertebrate Dentition

Vertebrate teeth and how they respond to environmental challenges play a crucial role in organismal prey capture and food processing. However, the morphology of teeth is not completely genetically determined as phenotypic plasticity in response to environmental conditions can heavily influence tooth anatomy in various vertebrate species. Plasticity is also highly important in structuring how the dentition, or the entire array of teeth an individual exhbits, function together. For instance, since most vertebrates are polyphydont (e. g. fish) the forces that food items exert on teeth can change during the replacement of old teeth. Some cichlid species are known to adapt to hard food items by increasing the size of replacement teeth for greater force resistance. Other di- or monophydont vertebrates use plasticity seemingly adaptively without replacing their dentition. Monophydont rodents are adapted to the high wear their incisors are subjected to by constantly growing those teeth and effectively sharpening them. Human dentition is also exposed to high degrees of plasticity for example during tooth development where environmental factors such as malnutrition can impact traits such as the timing of tooth eruption. I will discuss these examples as well as general patterns and processes involved in the plasticity of vertebrate teeth. As in few other traits, a better understanding of the plastic nature of teeth and the forces generating these induced phenotypic differences should allow us to better integrate studies of development, evolution, and behavior in both extinct and extant vertebrate taxa.

44-3 KARASOV, WH*; DEHNERT, GK; University of Wisconsin, Madison; *wkarasov@wisc.edu*

Non Target Impacts of the Herbicide 2,4,-D on Early Life Stages of Fish

2,4-dichlorophenoxyacetic acid (2,4-D) is contained in many systemic herbicides used worldwide for selective weed control of invasive plants in agriculture and aquatic ecosystems. The US Environmental Protection Agency (EPA) permits aquatic 2,4-D amine applications up to 2ppm for whole-lake treatments with a follow-up treatment 21 d after initial application. For multiple native WI fish species, we exposed early life stages (embryos and/or larvae) and juvenile fish to environmentally relevant concentrations of 2,4-D (0-2ppm) as the active ingredient alone and as the commercial formulations that are applied in the field. Survival was depressed by 2,4-D exposure for at least one early life stage in 78% of species tested (n=9); there were no impacts on juvenile fish survival in 5 species tested. In functional studies, 2,4-D interacted with neurobehavioral and endocrinological physiological systems. For example, in larval zebrafish, exposure to a 2,4-D commercial formulation reduced neural activity within the optic tectum and decreased prey capture ability, and this essential survival behavior was also depressed in larval yellow perch (Perca flavescens). In one type of endocrine study with juvenile fathead minnows (Pimephales promelas) raised in 0.05 ppm 2,4-D, whole-body cortisol rise following a stress challenge (momentary removal from water) was reduced >50%. These multiple lines of evidence underscore previously unappreciated risks associated with current 2,4-D application practices. Although designed to act against plant biochemical/physiological systems as a cell growth deregulator, 2,4-D joins other major herbicides such as atrazine and glyphosate as having surprising, significant non-target effects on function and survival of aquatic vertebrates. Work supported by the WI Dept. Natural Resources.

4-6 KASOJU, VT*; SANTHANAKRISHNAN, A; Oklahoma State University; *askrish@okstate.edu*

Bristled wings in fling: aerodynamic importance of initial inter-wing spacing

Tiny flying insects of body lengths under 2 mm, such as thrips and fairyflies, possess bristled wings and use wing-wing interaction via the ‘clap and fling' mechanism to augment lift generation at chord-based Reynolds number (Re) on the orders of 1-10. When compared to solid wings, bristled wings have been shown to decrease drag required to fling wings apart. We used a dynamically scaled robotic platform fitted with physical bristled wing models to examine the aerodynamic importance of initial inter-wing spacing of bristled wings during fling. Three sets of motion profiles were considered: 1) wings purely rotating about their trailing edges; 2) pure translation of each wing at a fixed angle of attack (AOA); and 3) overlapping rotation and translation of each wing, all at Re=10. The results show that (i) average drag coefficient increased during pure rotation and pure translation with increasing AOA (relative to horizontal), (ii) decreasing initial inter-wing spacing increased the lift coefficient due to formation of weaker trailing edge vortices, resulting in asymmetric leading and trailing edge vortices. Previous studies have shown leakiness of flow through bristles to aid in decreasing drag. However, we found that both peak drag and leakiness increased with decreasing initial inter-wing spacing during pure rotation. We observed large negative pressure distribution along the chordwise direction within the cavity between the two wings, which we suspect causes fluid to leak through the bristles. This suggests that increasing leakiness does not necessarily decrease drag during pure rotation in early fling. The contribution of leakiness to pressure and viscous drag reduction will be presented.

30-5 KATIJA, K*; GOVINDARAJAN, A; LLOPIZ, J; WIEBE, P; BREIER, J; HOBSON, B; RISI, M; ROBISON, B; ROCK, S; YOERGER, D; Monterey Bay Aquarium Research Institution, Moss Landing, CA, Woods Hole Oceanographic Institution, Woods Hole, MA, Stanford University, Palo Alto, CA; *kakani@mbari.org*

Mesobot: Toward autonomous observations of organismal behavior in the ocean's midwaters

Animals in the ocean's midwaters are some of the least understood organismal systems due to the technological challenges of non-invasively observing behavior in an exceedingly remote place. To address this need, we developed a new hybrid (remotely and autonomously operated) underwater vehicle called the *Mesobot*. Rated to 1000 m, this vehicle is designed to track and observe slow-moving midwater animals (e.g., salps, jellies, crustaceans) with minimal disruption. After acquiring animal targets under teleoperated control through a tether, the tether is released and the vehicle autonomously tracks targets for up to 24 hrs. While the *Mesobot* had its first deployments in 2019, we will present preliminary results from field trials that utilized the *Mesobot*'s stereo imaging hardware and *JellyTrack* algorithms on ROV *MiniROV* in Monterey Bay. Long duration observations of an amphipod (*Phronima sedentaria*) in a salp barrel and a feeding siphonophore (*Lychnagalma utricularia*) clearly illustrate the challenges and highlight the potential a vehicle like *Mesobot* will have on our understanding of midwater inhabitants.

15-8 KATZER, AM*; WESSINGER, CA; HILEMAN, LC; University of Kansas; *a681k477@ku.edu*

Nectary size is a pollination syndrome trait in Penstemon

Individual trait adaptation can influence the evolution of complex phenotypes such as floral pollination syndromes. In *Penstemon*, hummingbird-adapted flowers have evolved many times from bee-adapted ancestors. We examined the definition of *Penstemon* pollination syndromes in context of nectar volume and nectary development. Across 19 *Penstemon* species, we tested the evolutionary association of nectar volume and nectary area with pollination syndrome where we found both traits having an association with pollination syndrome. Then, we assessed the cellular-level processes shaping nectary area by measuring the width of 5 nectary cells in selected species, where we found a combination of cell expansion and cellular proliferation. Lastly, we assessed trait correlations in a segregating population from an intersyndrome cross and found that nectary area, nectar volume, and stamen length were all correlated with one another. These results show independent origins of hummingbird syndrome in *Penstemon* have parallel developmental processes in nectary patterning.

60-3 KATZ, HR*; MCCARTHY, NA; FOUKE, KE; MORGAN, JR; Marine Biological Laboratory, Woods Hole, MA, Carthage College, Kenosha, WI; *hkatz@mbl.edu*

Functional Recovery of Burrowing Behavior in Sea Lampreys After Spinal Cord Injury

Following a complete spinal cord transection, larval sea lampreys (*Petromyzon marinus*) are able to regenerate their spinal cords in 10-12 weeks post-injury (WPI), and consequently undergo functional recovery of swimming. However, larval lampreys are generally found burrowed in the substrate of their home environment (e.g. sand). While recovery of swimming is robust and well-established, the lampreys' ability to recover burrowing following spinal cord injury is largely unknown. Burrowing behavior has two components. The initial component resembles swimming with propagated undulations, while the final component involves large body flexions that pull the tail under the sand. Here, we evaluated the lampreys' ability to burrow by examining these two components from video recordings at multiple post-injury time points during recovery from spinal cord injury, spanning from 1 to 11 WPI. Control (uninjured) animals completed the initial component in 1.82 ±1.24 seconds (N=16) and the final component in 21.13 ±15.95 seconds (N=15). Transected animals did not attempt to burrow until 2 WPI and most animals from 2 to 8 WPI were unable to burrow completely, leaving a portion of the tail exposed. Burrowing coverage improved over time with most animals burrowing completely by 9-11 WPI. The duration of the initial component did not differ between control and spinal-transected animals across the entire recovery period, but the duration of the final component in 9-11 WPI transected animals (94.93 ±81.76 seconds, N=15) was significantly longer than in controls. These data indicate that, similar to swimming behavior, lampreys are able to recover burrowing behavior after spinal cord injury, though moderate deficits may persist.

62-7 KAWANO, SM*; BLOB, RW; George Washington Univ., Clemson Univ.; *smkawano@gwu.edu*

Evaluating limb bone stresses of early tetrapods in the context of the evolutionary invasion of land

Becoming terrestrial was a pivotal event in vertebrate evolution that placed new physical demands on the musculoskeletal system. Increased gravitational loads on land can make bones more prone to injury, but how stressful was terrestrial locomotion for early tetrapods? We used a computational model to estimate the magnitude of peak bone stresses, across limb postures ranging from hyper-sprawling to upright, by integrating experimental data from live animals with morphological data from fossils. Although salamanders are often used to model some of the earliest tetrapods due to their generalized tetrapod Bauplan, they may better represent stages that occurred later in the transition to land. Our laboratory studies show that a semi-aquatic salamander (*Pleurodeles waltl*) had a hyper-sprawled limb posture compared to the terrestrial tiger salamander (*Ambystoma tigrinum*), with ground reaction forces intermediate between semi-aquatic mudskipper fish and terrestrial *A. tigrinum*. When these data were used in our computational model of a crownward early tetrapod (*Greererpeton burkemorani*) using a salamander-like gait, femoral stresses decreased as the limbs became more sprawled. Moreover, stresses were lower when *Greererpeton* was modelled with limb mechanics resembling those of salamanders rather than alligators, supporting salamanders as a reasonable model for *Greererpeton*. Our results also indicate that the estimated peak stresses on the *Greererpeton* femur never exceeded typical values of ultimate bending strength for amphibian limb bones, suggesting appendicular bones were likely well suited for terrestrial locomotion relatively early in their evolution. These analyses set the stage for further evaluations of limb posture and terrestrial locomotor capacity across the water-to-land transition.

35-5 KAY, DI*; GIGNAC, PM; O'BRIEN, HD; Oklahoma State University Center for Health Sciences, Tulsa; *david.kay@okstate.edu*
Do sockets shape teeth in non-mammalian thecodonts? A case study in Alligator mississippiensis
In heterodont mammals, the alveolus mechanically shapes and adds complexity to the developing crown (e.g. rodents). In crocodylians, which are also thecodont but with pseudoheterodont crown shapes (i.e. two broad categories: caniniform, molariform) it is unclear if alveolar form similarly determines crown morphologies. Here we examine alveolar shape alongside crown type to test for a relationship between sockets and crowns in *Alligator mississippiensis* for the first time. From CT data, we digitally reconstructed alveoli of the most procumbent caniniform and molariform teeth, as well as ambiguously shaped intermediate teeth. Alveolus outlines were quantified using elliptical Fourier transformation, standardizing for location, orientation, and size. Principal components analysis (PCA) ordinated patterns in the Fourier coefficients, and linear discriminant analysis (LDA) was run on the PC scores to determine consistency of crown categories: caniniform, molariform, and intermediate. The first two PCA axes captured ~87% of shape variance (PC1 = relative mesio-distal alveolar length, PC2 = alveolar curvature). Crown-shape categories fell into largely separate convex hulls. The LDA had high classification rates for caniniform (80%) and molariform (90%) teeth, but middle teeth were less well-defined (60% accurate identification, with the remaining 40% mis-classified as caniniform). These preliminary results suggest a significant relationship exists between alveolar and crown morphologies in crocodylians. Intriguingly, each new tooth in these polyphydont reptiles contributes tissue to the socket wall (e.g. interalveolar bone), thus potentially shaping subsequent crown generations and resulting in a mechanism inverted from the mammalian pattern (e.g. crown-first vs. alveolus-first).

6-3 KéVER, L*; BASS, AH; PARMENTIER, E; CHAGNAUD, BP; Liège University, Liège, Belgium , Cornell University, Ithaca, U.S.A. , Liège University, Liège, Belgium, Ludwig-Maximilian University, Munich, Germany;University of Graz, Graz, Austria; *loic.kever@uliege.be*
Conserved Neural Circuitry among Mochokid Catfish despite Morpho-Functional Diversity of Sonic and Electric Organs
The Elastic Spring Apparatus (ESA), composed of the protractor muscle (PM) and a modified process of the fourth vertebra (i.e. Müllerian ramus), evolved independently in several catfish families. In most taxa, its function is sound production, but the PM of some synodontid mochokids has been modified to produce electric discharges. Here, we compare the ESA behavioral phenotype, morphology, and associated neural circuit between three synodontid species producing sounds (*Synodontis grandiops*), electric discharges (*S. nigriventris*), or both (*S. eupterus*) and representative members of two sister genera - *Microsynodontis batesii* and *Mochokiella paynei*. *Microsynodontis batesii* and *M. paynei* produce only sounds suggesting that electric signaling evolved only among synodontids. Together, the ESA of the five species shows large interspecific differences in size and shape including intergeneric differences in the PM insertion points, while *S. nigriventris* has the thinnest PM and a Müllerian ramus with the longest stem and shortest plate. Despite some quantitative differences, tract tracing after labelling of the PM with neurobiotin or dextran biotin reveals similar organizational patterns in the ESA neural circuit for the five species. In every case, paired motor and premotor nuclei are positioned at the same location in the caudal hindbrain. Despite dramatic differences in the behavioral phenotype and anatomy of the ESA, the central ESA neural circuit of these five species seems highly conserved. Research support from the NSF (IOS-1656664 to AHB), DFG (BPC), and F.R.S-FNRS (LK).

99-3 KEHL, C E*; WU, J; LU, S; DRUSHEL, RF; SMOLDT, R K; CHIEL, H J; University of North Carolina at Chapel Hill, Case Western Reserve University, 1973; *cekehl@email.unc.edu*
Effect of the Sub-radular Fibers on Grasper Opening in Aplysia californica
The mechanics of grasping soft, and irregular material is challenging for both biological and designed systems. Many animals have evolved to meet this challenge. In particular, the feeding system of the marine mollusk *Aplysia californica*, an herbivore generalist, allows it to grasp and eat seaweeds of different textures, toughness and shapes. The surface of the grasper is known of as the radula, a cartilaginous sheet with fine teeth. Previous *in vitro* studies suggested that the I7 muscles, deep in the grasper, were responsible for the opening of the radula. Lesions to these muscles do not prevent animals from grasping and ingesting food. New *in vivo* studies demonstrate that a previously uncharacterized set of fine muscular fibers - the sub-radular fibers (SRFs) - mediate openings even in the absence of the I7 muscles. Both *in vivo* and *in vitro* studies show very large deficits in opening when the SRFs are lesioned. A theoretical biomechanical analysis of the actions of the SRFs suggest that they reverse the folding of an anatomical crease to create an arched shape that can conform to irregular structures.

12-2 KELLY, JB*; THACKER, RW; Stony Brook University, Stony Brook, NY; *joseph.b.kelly@stonybrook.edu*
Ecological divergence in the sponge genus Ircinia
Microbiomes can have substantial impacts on the ecological identities and evolutionary histories of their hosts. In the sponge genus *Ircinia*, evolutionary responses to host-microbial symbioses abound, evidenced through several hallmarks of metabolic integration including microbial genome streamlining, the translocation of nutrients between the microbes and hosts, and the heritability of endosymbionts. Previous work has shown that several incipient *Ircinia* species from Panama are divergent in the compositions of their microbiomes (2bRAD, 16S rRNA data). However, the ecological ramifications of these microbiome differences are largely unknown due to the inherent limitations of 16S rRNA data and the lack of ecophysiological information for the vast majority of these microbes. Our study sought to fill this gap in knowledge by using shotgun-metagenomic data to delineate the metabolic consequences of *Ircinia* microbiomes.

23-2 KELLY, PW*; PFENNIG, DW; PFENNIG, KS; UNC Chapel Hill; *patk@live.unc.edu*

Sexual Selection and Adaptive Evolution in Variable Environments: Phenotypic Plasticity as a Good-Genes Effect

What is the role of sexual selection in adaptive evolution? Theory, modeling, and data tell us that sexual selection can facilitate adaptive evolution by favoring specific traits that are also favored by natural selection, by purging deleterious mutations, and by favoring high-condition individuals that can achieve high fitness in a range of environmental conditions. These scenarios are complicated, however, by variable or novel environments, in which sexual selection can fail to track changes in natural selection, thereby becoming an impediment to adaptive evolution. We propose another route whereby sexual selection can facilitate adaptive evolution. In particular, we present observational and experimental data that suggest that offspring plasticity can function as an indirect benefit of mate choice and that sexual selection can thereby facilitate adaptation in variable or novel environments by promoting the evolution of adaptive plasticity.

101-8 KELLY, TR*; BOYER, A; MACDOUGALL-SHACKLETON, EA; MACDOUGALL-SHACKLETON, SA; Louisiana State University, Western University; *trkelly@lsu.edu*

Experimental acute-phase immune activation in migratory sparrows has host-antigen specific effects on body mass and migratory restlessness

How birds contribute to the global spread of disease depends inherently on the physiological and behavioral responses of the host to pathogenic invasion. This is particularly critical during migration when birds traverse large geographic barriers and interact with con/hetero-specifics. Observational studies of how pathogens affect migrating birds are limited in that captures of migrants at stopover provide a single snapshot of the subject in time. These can rarely distinguish the costs of infection from the costs of mounting an immune response, nor can they ascertain the effects of pathogen exposure without subsequent infection. Understanding host-specific responses to antigen exposure is important in modeling super-individual scales of host-pathogen dynamics. We experimentally challenged song sparrows (n=28; *Melospiza melodia*) and white-throated sparrows (n=27; *Zonotrichia albicollis*) in autumn migratory condition with non-infectious antigens, then monitored body composition and nocturnal migratory restlessness. Whole body mass of both species increased the day after birds were challenged with lipopolysaccharide (LPS) or keyhole-limpet hemocyanin (KLH), substances that induce an acute-phase immune response. Migratory activity of all sparrows, including sham controls, was reduced the night after receiving treatments. White-throated sparrows, but not song sparrows, challenged with LPS had increased lean mass one week after exposure and KLH-challenged white-throated sparrows exhibited reductions in migratory activity during the week of recovery. Our results suggest that short-term activation of the acute immune response may have effects on migratory condition and activity, specific to certain combinations of hosts and antigens.

81-7 KEMP, ME; The University of Texas at Austin; *mkemp@austin.utexas.edu*

Extinction, persistence, and resiliency in the Caribbean fossil record

The Caribbean is one of the most well-studied biodiversity hotspots, regions that in total cover less than 3% of the Earth's surface yet host the majority of the planet's endemic species. But the diversity of today's Caribbean is only a fraction of what once existed there, as climate, sea-level fluctuations, and multiple human colonization events have restricted the ranges of many species, or worse, contributed to their extinction. Given this past history of environmental perturbations, paleobiology is well-suited to inform ongoing conservation needs in this system. Such perspective from the past is essential now more than ever before, as continued habitat degradation, non-native species introductions, and ongoing range contraction, extirpation, and extinction threaten to erode the remaining biodiversity. My research explores how one seemingly successful group of Caribbean vertebrates, the lizards, have been impacted by environmental perturbations throughout the Pleistocene, Holocene, and into the Anthropocene. I unveil extinction biases within the Caribbean that have transformed how we understand lizard extinctions globally. I also report on the excavation of a paleontological site in Puerto Rico that encompasses the past 20,000 years. Data analyzed from the site are concordant with overarching trends in the Caribbean fossil record: most notably, the large-scale extinction of terrestrial non-volant mammals and fewer losses in other taxonomic groups, such as lizards. Detailed stratigraphic records provide evidence of long-term site occupation for many *Anolis* species, although preliminary data suggest an instance of turnover in this genus. This newly described paleontological data highlights both the vulnerability and resiliency of lizards and Caribbean vertebrates more broadly, with relevance to regional conservation management.

64-6 KEMP, AK; Duke University; *addisonkemp@gmail.com*

Effects of binocular field size on leaping performance in small bodied primates

It has long been argued that a number of distinguishing features of primates, including their forward-facing eyes and large binocular visual field, improve the effectiveness of arboreal leaping locomotion, especially in a thin branch setting. This remains an area of intense debate, especially in regards to primate origins, yet this study is the first to directly test the relationship between binocular field size and leaping performance in primates experimentally. The effect of restriction of the binocular field on leaping locomotion was evaluated in five captive *Cheirogaleus medius*, a small bodied (~175g) nocturnal primate species considered a reasonable morphological and ecological analogue of early primates. Binocular field restriction was achieved using a helmet-mounted blinder that obstructed the medial portion of the visual field of one eye. Subjects were recorded leaping between narrow vertical substrates both with the full use of their binocular field and with a restricted binocular field. Restriction of the binocular field did not increase the subjects' probability of either missing or failing to reach a landing substrate. Restriction of the binocular field did, however, increase the probability of adverse landings, the number of grasp adjustments individuals made between consecutive leaps, and the lag time between landing and subsequent take-off. These results suggest that increases in binocular field size during early primate evolution may have provided an important advantage in leaping by facilitating more precise landings.

114-6 KENALEY, CP*; KRAEMER, K; KUNKLE, H; Boston College; *kenaley@bc.edu*

Revisiting the Kinematic Parameters that Define Eel-like Swimming

The kinematics of aquatic locomotion in elongate, eel-like vertebrates has received considerable attention since the pioneering work of Sir James Gray in 1933. In recent decades, the body of research focusing on eel-like locomotion suggests collectively that this mode of locomotion is highly variable with respect to midline kinematic parameters. In this study, we summarize these patterns and add new insights concerning propulsive wavelength and wave speed. Synthesizing data from previous work with new kinematic analysis of hundreds of thousands of waveforms over a range of routine, steady swimming speeds from two eel-like swimmers, the American eel (*Anguilla rostrata*) and ropefish (*Erpetoichthys calabaricus*), and one subcarangiform swimmer, rainbow trout (*Oncorhynchus mykiss*), we show that there may be novel canonical patterns of eel-like swimming that set this mode apart from other modes of aquatic undulatory locomotion. Specifically, our dataset and data from previous studies of eel-like swimmers, indicate that eel-like swimming may be defined by rostocaudal gradients of increasing propulsive wave speed and decreasing propulsive wavelength. In contrast, a subcarangiform mode, as represented by the rainbow trout, is defined by a rostrocaudal gradients of decreasing wave speed and increasing wavelength.

9-2 KENNEDY, J.R*; MAHADEVAN, L; NAGPAL, R; Harvard University, Harvard Unisersity; *jokennedy@g.harvard.edu*

Mapping spatiotemporal changes of North American beaver (L. Castor canadensis) damming complexes

Beavers construct structurally complex and dynamic damming networks.In many cases, it is difficult to understand the building process of beavers because it happens over many years and satellite imagery does not provide sufficient spatial or temporal resolution to track beaver damming network growth. In mountainous regions snow melt annually washes out the previous year beaver builds. Here, beaver colonies thrive by recapitulating the entire dam building process over a period of three to five months. This provides a unique opportunity to study the building process from "scratch". We hypothesize that beavers build locally and are driven to do so by hydraulic triggers at the dam scale. We present a study of beaver colony damming network construction in the foothills of the Rocky Mountains in northwestern Montana. Using 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, 13 beaver colonies responsible for the construction of 76 dams over a three month period following snow melt. Using Agisoft Photoscan high resolution orthomosaics were built and then annotated with ArcMap to create shapes files in order to track dam network formation and growth. A beaver damming network contains a multitude of features; including dams, ponds, trails, canals, lodges, and scent mounds. Our results suggest that the initiation of building corresponds to the measured volumetric flow rates at each site. The final damming complex is many times larger than any one individual beaver and likely taking place in many locations simultaneously, suggesting beavers engage in distributed building activities.

24-1 KERNBACH, M.E*; UNNASCH, T.R; MARTIN, L.B; University of South Florida; *Kernbach@mail.usf.edu*

Differential Effects of Spectral Composition of Nighttime Lighting on West Nile Virus Resistance and Mortality in House Sparrows

Artificial light at night, or ALAN, has become a pervasive anthropogenic stressor for both humans and wildlife over the past century. Although many of the negative impacts of ALAN on health have been documented, the consequences for infectious disease dynamics are largely unexplored. With the recent implementation of broad-spectrum and energy efficient light-emitting diodes (LEDs), the effects of spectral composition of ALAN have also come into question. Previous studies have shown that exposure to low levels of incandescent ALAN extends the infectious period of house sparrows infected with West Nile virus (WNV) without affecting mortality rates. Here, we asked whether altering the spectral composition of ALAN would exacerbate or ameliorate these consequences for house sparrows infected with WNV. We found that exposure to broad-spectrum (3000+5000K) LED ALAN did not affect viral resistance (i.e. inverse of viremia), but this light form increased WNV-induced mortality. As these same individuals died earlier and lost more body mass over time than expected from their viremia, higher mortality under broad-spectrum ALAN may be due to disproportionately higher pathogen-induced damage and/or immunopathology. Conversely, birds exposed to amber-hue (1800K) LED ALAN had significantly lower viremia, and mortality rates similar to natural light exposed controls. This study demonstrates that the spectral composition of ALAN can affect infection outcomes and thus provides insight into utility of particular nighttime lighting methods.

69-4 KHALIL, S*; ENBODY, ED; WELKLIN, JF; SCHWABL, H; WEBSTER, MS; KARUBIAN, J; Tulane U, Uppsala U, Cornell U, WSU, Cornell U; *skhalil@tulane.edu*

Testosterone Regulates Gene Expression Associated with Carotenoid-Based Plumage Ornamentation in the Red-backed Fairywren

For many animals, testosterone (T) activates ornamentation in males. However, our mechanistic understanding of the relationship between T and ornamentation is limited in two main ways: 1) T does not impact all tissue types in the same manner, and 2) sex-specific coloring is likely mediated by polygenetic interactions, rather than simple genetic variation. As a consequence, transcriptional differences—and how hormones may regulate them—are critical to understanding the link between genotype and phenotype. In this study, we investigate the role of testosterone in mediating gene expression across tissues associated with a sexual signal in wild Red-Backed Fairywrens (*Malurus melanocephalus*). In this species, males exhibit flexible reproductive phenotypes: some individuals have high circulating T and breed in red/black plumage, and others have low circulating T and breed in female-like brown plumage. Previous work has shown that females prefer mating with red/black males over brown males, and redder males have higher reproductive success, suggesting the red back is an important sexual signal. To assess how the endocrine system impacts gene regulation and red plumage production, we experimentally manipulated T levels in males and sequenced the transcriptome of both the liver and feather, two important tissues for red carotenoid coloration. We identified genes involved in generating variation in plumage color by comparing the transcriptome of control brown males, T-implanted brown males, and naturally red/black males. We found that testosterone regulates the expression of CYP2J19 in the liver, which is essential for carotenoid metabolism, while also mediating carotenoid transport into feathers. To our knowledge, this is the first study to demonstrate a causal link between testosterone and carotenoid metabolism in a wild population.

3-3 KHANDELWAL, P C*; HEDRICK, T L; UNC Chapel Hill; *pranavk@live.unc.edu*

Gliding through clutter – obstacle-avoidance and path-planning in the flying lizard Draco dussumieri

Gliding animals frequently traverse complex spatial habitats to perform ecologically relevant behaviors. However, unlike flapping flyers, gliders are constrained in their ability to negotiate obstacles and cover longer distances by a fixed energy budget (takeoff height) and a relatively simpler wing anatomy. In this context, it is unclear how gliders achieve collision-free flight on a day-to-day basis. We address this question by quantifying voluntary glides in a naturally behaving, wild population of the flying lizard *Draco dussumieri*, inhabiting the Agumbe rainforest nature preserve in India. We digitized 25 glide trajectories of varying distances in 3D and found that *Dracos* executed non-equilibrium glides involving a steeper takeoff, shallower mid-glide and a sharper pitch-up landing maneuver to cover longer glide distances. Furthermore, we digitized the location of all trees in the recording environment and found that for a given glide distance, *Dracos* selected a target tree with less surrounding clutter and jumped away from an obstacle in line with the target tree. During flight, *Dracos* navigated their cluttered environment using a vision-based obstacle-avoidance model with up to 0.5g turns. Finally, to land on the target tree, *Dracos* initiated deceleration consistent with a visual trigger model and progressively increased their braking while approaching the landing tree. In summary, we used a biologically relevant framework of the environment, sensory input and the biomechanical capability of *Dracos* to show how gliders execute collision-free flight in a natural habitat.

30-7 KHURSIGARA, AJ*; ESBAUGH , AJ; The University of Texas at Austin; *akhursigara@utexas.edu*

Does crude oil exposure alter behavior in fish?

Crude oil is a common environmental toxicant of concern in aquatic environments, and the impact it has on marine fishes has been well studied. A majority of these studies have focused on cardiotoxicity and its downstream ecological effects. However, recent work has demonstrated that neurological function and behavior may be just as sensitive as the cardiotoxic endpoints. Transcriptomic work from larval red drum (*Sciaenops ocellatus*) has shown significant alteration in pathways related to neurological and cognitive function following oil exposure; this was accompanied by a reduction in brain size. Based on this information, several follow up studies sought to examine the influence that oil exposure may have on fish behavior and performance. In open field tests, acutely exposed larval red drum showed a reduction in thigmotaxis or "wall hugging" behavior and increased area explored compared to control conspecifics. Similarly, small shoals of Atlantic croaker (*Micropogonias undulatus*) in an open field test also demonstrated a reduction in thigmotaxis while increasing mean neighbor distance, suggesting a decrease in sociability. While these studies examined specific personality behaviors, recent work on zebrafish (*Danio rerio*) has examined the effect of oil on behavioral syndromes. Interestingly, preliminary data does not suggest a shift in behavioral syndromes following oil exposure, however there is a shift in the correlation between behavioral traits. These findings suggest that more research is needed to understand how sub-lethal exposure can impact fish behavior and the downstream ecological significance this can have for populations.

S9-3 KIENLE, SS*; POWERS, J; CACANADIN, A; KENDALL, T; RICHTER, B; COSTA, DP; MEHTA, RS; UCSC; *skienle@ucsc.edu*

Linking Functional Morphology, Behavior, and Ecology to Understand Foraging Strategies in an Endangered Marine Mammal

Successful animals integrate morphology and behavior to produce diverse feeding strategies to consume prey in a variety of environmental contexts. Different strategies represent trade-offs between morphological specialization, prey choice, and energetic expenditure, and comparing strategies and their trade-offs is important for understanding individual and population level foraging success. Here we examined the underwater feeding strategies used by the endangered Hawaiian monk seal (*Neomonachus schauinslandi*), as poor foraging success seems to be driving the decline of some populations. Seven Hawaiian monk seals were fed five prey types of different sizes presented in three contexts (surface, midwater, benthos). Hawaiian monk seals used two strategies: suction feeding and biting, and these strategies involved specific behaviors and kinematics. Despite having a skull and dentition specialized for biting, Hawaiian monk seals used suction feeding most frequently (91% of all feeding trials), regardless of prey type and feeding context. However, biting was used most frequently when seals targeted larger prey (>70% of the seal's head length), demonstrating that prey size influences the transition between strategies. In terms of trade-offs, suction feeding was 2.3 times faster than biting and involved a smaller gape and fewer jaw movements, allowing seals to quickly consume numerous small prey; biting was slower but resulted in 1.5 times more energy gained per time spent feeding. Maintaining both strategies results in increased behavioral flexibility, which is important as Hawaiian monk seals feed in an increasingly spatially and temporally dynamic marine environment.

76-7 KIKEL, M*; GECELTER, R; THOMPSON, NE; NYIT College of Osteopathic Medicine; *mkikel@nyit.edu*

Evolutionary origins of human pelvic list, hip adduction, and step width

Human bipedal walking entails unique frontal plane balance strategies compared to other primates. Compared to bipedal chimpanzees, humans walk with step widths that are proportionally three times narrower, utilize stance-phase hip adduction rather than abduction, and use a pattern of pelvic drop on the swing side rather than swing-side pelvic elevation. Here we sought to determine if and how the human-like pattern of pelvic and hip motion is related to step width. To investigate pelvic and hip motion during walking, ten human subjects walked on a treadmill at narrow, normal, and wide step widths. Full body kinematics were measured using the Plug-In Gait marker set with a 12-camera Vicon motion capture system. Our results suggest that neither wide steps (~3 times normal width) nor narrow steps (~0 cm) lead to major differences in pelvic list. Narrow and wide steps do lead to an increase and decrease, respectively, in overall hip adduction (+3° for narrow steps, -6° for wide steps). These results suggest that the human-like pattern of pelvic list is not dependent on step width, though hip adduction is. The change to pelvic drop on the swing side in humans and perhaps some early hominins was therefore likely an evolved trait, and not a direct result of the emergence of valgus knees and narrow step widths.

16-4 KILLION, KD; Blinn College District, Brenham, TX, Blinn College; *karen.killion@blinn.edu*

Getting Undergrads to Write the Something

Getting undergraduates to take notes is a struggle. They either write nothing or attempt to write every word. I have a background in teaching 6-12 science and have done professional development for K-12 classroom teachers for a several years. I constantly try methods and strategies from secondary levels in my classroom. One thing I've recently tried is making study tools that seem more like an activity that actually learning the content or taking notes. In lower grades "foldables" are often created and kept in a composition book using lots of construction paper, colored paper and markers, etc. I call the ones we make in my classes, grown-up foldables. White paper and a pencil or pen do just fine unless the student wants to "decorate" theirs. I let them know they are not graded, they are their creations and their study tools. Sometimes we make the foldable as a class as we go through the lecture and sometimes I put pictures of a sample on our digital platform and encourage them to make a foldable on their own as a way to study. I tried this with my 2019 Summer I Non-Majors Biology class and when the students came in for the final, they had all their foldables to continue reviewing for the exam. Students in that class even suggested other topics that would be good in a foldable. I'm not a research scientist. I have no data. I am a hand-on, brains on, non-majors, community college biology educator trying to make students realize they need to know some basic biology. If they have a little fun, make a "flappy thing" as one student called it, and learn something, it's a success!!

35-6 KIM, SL*; YEAKEL, JD; EBERLE, JJ; ZEICHNER, SS; University of California, Merced, University of Colorado - Boulder, California Institute of Technology, Pasadena, CA; *skim380@ucmerced.edu*

Impacts of Environmental Gradients on Shark Body Size: a Comparison from Fossil Evidence and Demographic Modeling of Sand Tigers

Fossil shark teeth serve as biological proxies for numerous environmental and climatic variables but, geochemical records are not often correlated to ecological factors. For example, the oxygen isotope composition of shark enameloid (^{18}O) acts as an indicator of water temperature and salinity. In addition, tooth crown height correlates to body size and the vast number of fossil teeth in museum collections can be used to provide estimates of body size distributions for extinct populations. Changes in body size distributions over space and time are, in part, a consequence of changes to shark life history in response to shifting environmental conditions. We determined body size and ^{18}O values for Eocene Sand Tigers (*Striatolamia macrota* syn. *Carcharias macrota*) from two high latitude (Arctic and Southern Ocean) and two mid-latitude (Gulf of Mexico) localities to compare the effects of latitude, temperature, and salinity on life history. We found significant differences in body size distributions across sites differing in environmental conditions as well as function, as some locations are suggested nurseries. We created a demographic population model to evaluate how temperature likely constrained growth and reproduction of a population straddled between spatially separate nursery and adult sites. By comparing the body size distributions of empirical fossil data with results from our demographic model, we are poised to assess the role of environmental plasticity in the long term evolutionary success of Sand Tigers.

92-2 KIMBALL, MG*; GRANT, AR; CHRISLER, A; JOHNSON, E; MALISCH, JL; Louisiana State University, Baton Rouge, LA, University of Nevada, Reno, NV, St. Mary's College of Maryland, St. Mary's City, MD, St. Mary's College of Maryland, St. Mary's City, MD; *mkimba6@lsu.edu*

Acute Stress Mobilizes Glucose and Free Fatty Acids in Mountain Dark-eyed Juncos (Junco hyemalis)

Resource mobilization and reallocation is a major endpoint of the physiological response to acute stress. However, energy metabolites have not been the focus of most field studies. Here we characterized the glycemic and free fatty acid (FFA) response to acute-handling stress in a breeding, free-living, population of Mountain Dark-eyed Juncos (*Junco hyemalis*) in Mono County, CA. Juncos were trapped in seed-baited Potter traps at Tioga Pass Meadow from May 17 to June 20, 2018, coinciding with territory establishment and the early nesting period. Blood samples were collected at 0, 15 and 30 min post-capture. Blood glucose levels were higher than baseline at 15 min (43% increase) and 30 min post-capture (67% increase). FFA levels were also higher than baseline at 15 min (29% increase) and 30 min post-capture (22% increase). Predictors of energy mobilization including date, scaled body mass, fat score, hematocrit, sex, and bleed delay time were modeled using backward and forward stepwise regression. Analysis showed that juncos mobilize glucose and FFA in response to acute handling stress, and these responses are best modeled when scaled mass, abdominal fat, and initial glucose response from baseline to 15 min are included as predictor variables. These results suggest that energy mobilization capacity is influenced by measures of body condition.

S4-8 KIMMITT, AA*; SINKIEWICZ, DM; KETTERSON, ED; Texas A&M University, Indiana University; *akimmitt@bio.tamu.edu*

Female Songbirds that Differ in Migratory Strategy Also Differ in Neuroendocrine Measures in Early Spring

Most studies of reproductive timing and the underlying mechanisms have used only male subjects, despite the critical role females play in determining breeding phenology. To better understand how animals shift into the reproductive state, more knowledge of hormonal mechanisms in the brain underlying the transition is necessary, especially in females. Closely related populations found in the same environment in early spring that differ in reproductive timing provide an opportunity to examine differences in these mechanisms. We studied a migrant and resident population of dark-eyed juncos (*Junco hyemalis*) that are found in overlapping ranges during the winter and early spring. Populations differ in reproductive timing, as residents initiate breeding before migrants depart, whereas migrants do not breed until they reach northern breeding grounds. To study differences in the hypothalamic mechanisms of reproduction, we caught 16 migrant and 13 resident free-living females between March 25 and April 11. We quantified expression of mRNA transcripts for genes related to reproduction in the hypothalamus. We found that resident females had higher abundance of gonadotropin-releasing hormone transcripts than migrant females, indicating that residents have greater hormonal top-down stimulation than migrants during this time. Additionally, we found higher transcript abundance of estrogen receptor and androgen receptor in migrant than resident females, suggesting that negative feedback might delay reproductive development in migrants. These differences in hypothalamic mechanisms could help to explain population differences in reproductive timing.

46-5 KIMURA, J*; RICCI, L; LUO, Y; SRIVASTAVA, M; Harvard University; *Julian_Kimura@g.harvard.edu*

Development of the acoel worm Hofstenia miamia and the embryonic origin of neoblasts

Animals that are capable of "whole-body" regeneration are able to replace any missing cell type. Species that are able to undergo whole-body regeneration often do so using a population of adult stem cells that are effectively pluripotent such as the i-cells of cnidarians and neoblasts of planarians. Studying the embryonic origins of these adult stem cells in regenerative species would be the first step in determining the genetic control of stem cell formation. We are studying this question using the new model system Hofstenia miamia, a highly regenerative acoel species that produces experimentally tractable embryos in the laboratory. Hofstenia possess a population of stem cells, also called neoblasts, that are necessary for regeneration and express homologs of piwi. Here, we report an in-depth characterization of embryonic development in Hofstenia miamia. We generated a bulk RNAseq dataset and a developmental atlas by studying gross morphological changes and cellular movements during Hofstenia embryogenesis. A previously undescribed, coordinated cellular movement occurred at about 43-55 hours post laying where the cells on the surface of the animal pole became internalized ("Dimple" stage). in situ hybridization revealed that differentiated cell types and body axes were detectable after the Dimple stage. Finally, to determine when neoblast-like cells emerge during embryogenesis, we performed single cell RNA-seq across developmental stages. Using computational tools, we aim to identify cell lineages and the genes that are required for neoblast formation. The identification of candidate regulators followed by functional studies will enable us to determine the mechanisms for neoblast specification during embryogenesis.

77-8 KING, EE*; STILLMAN, JH; WILLIAMS, CW; University of California, Berkeley, University of California, Berkeley and San Francisco State University; *emily_king@berkeley.edu*

New Zealand Mud Snails Continue Respiring During Severe Oxygen Limitation at Warm Temperatures

Physiological intolerance of environmental stress constrains a species' range by limiting population growth and dispersal to new habitats. Abiotic stress also serves as a barrier to establishment of non-native species. Understanding the interactive effects of temperature and oxygen on aquatic habitats is critical to predicting habitat availability across present and future landscapes. The invasive snail, *Potamopyrgus antipodarum*, tolerates diverse abiotic conditions across its global distribution, but how habitat temperature and oxygen availability interactively affects its distribution is unknown. This study investigated the effect of water temperature and oxygen saturation on respiration rate to discern under what conditions persistence would be limited. We predicted that respiration rates would increase with temperature and that respiration rates would decrease with decreasing oxygen supply. Respiration rates were measured during progressive hypoxia, from 100% O_2 until respiration ceased, at 9 temperatures (7-35°C). As predicted, we found that respiration rates declined with decreasing water temperature and decreasing oxygen availability. At warmer temperatures snails continued respiring under increasingly hypoxic conditions (<1.5mg/L O_2) while they stop earlier at lower temperatures (1.5-3 mg/L O_2). Thus, faster respiration rates were associated with a more complete use of available oxygen. At low temperatures there is still oxygen remaining suggesting that snails have stopped respiring through active regulation rather than conforming respiration rates to the oxygen supply available. However, at high temperatures the only option is to use the remaining oxygen.

10-4 KING, TK*; BROWN, JM; Louisiana State University ; *tking21@lsu.edu*

Identifying Atypical Modes of Continuous Trait Evolution

Phylogenetic comparative methods (PCMs) are used to make comparisons among organisms while considering their shared evolutionary histories. Brownian motion (BM) and the Ornstein-Uhlenbeck (OU) process are the main models of continuous trait evolution utilized in the context of PCMs. However, because PCMs can be applied to a wide range of organisms occupying a number of environments and various spans of evolutionary time, these models may not be able to fully capture all observed patterns of trait evolution. How valid are your biological conclusions if characters of interest do not conform to either mode of evolution? Here we propose a new parametric bootstrapping method using phylogenetic contrast to assess the fit of either BM or OU models to continuous traits. Phylogenetic contrasts were calculated for each trait of interest along the tree and used as a test statistic. We performed simulations using estimated parameters after fitting each trait to either BM or OU. We used effect size to compare phylogenetic contrast between empirical and simulated datasets. We applied this method to data on seven structural, temporal and frequency characteristics of birdsong from the genus Catharus. Surprisingly, comparisons indicate that neither BM or OU models properly characterizes the mode of evolution, as evidenced by high effect size values. Additionally, this method allows for the identification of specific outlier nodes that contrast with what we would expect if the tree where evolving under BM or OU models. To verify our method, we performed a small simulation study to demonstrate that it has a proper Type I error rate. Ultimately, this study highlights the importance of carefully considering other possible modes of evolution.

23-3 KING, RW*; WUND, MA; FOSTER, SA; BAKER, JA; Rich King, Clark University, Worcester, MA, The University of New Jersey, Clark University, Worcester, MA, Clark University, Worcester, MA; *rking@clarku.edu*

Salinity mediated shape plasticity in oceancic threespine stickleback

Adaptive radiations offer unique insights into evolutionary processes and elucidating the processes by which the evolution of new species occur. Parallelism in adaptive radiations could be the result of selection acting on standing genetic variation or via a 'flexible stem system' that causes the expression of consistently different phenotypes in different environments. Subsequent selection could produce ecotypic differences in adaptive radiations and thus the high levels of parallelism in these radiations. Evaluation of these alternatives is difficult, as comparison of ancestral genetic architecture or patterns of plasticity with those of derived, divergent ecotypes is rarely possible - primarily because the ancestral form is rarely extant. Using the threespine stickleback adaptive radiation, we employ a common-garden design and geometric morphometrics to test degree of plasticity in shape between marine and anadromous (i.e., ancestral) populations based upon salinity of the rearing environment. Our study indicated that the form of plastic responses differs between anadromous and marine G. aculeatus. Moreover, there was clear evidence that some of the shape variation between anadromous and marine fish is due to trait-based genetic differentiation. To the best of our knowledge, this is the first suggestion for any evolutionary system where two, differentially plastic, ancestral stems exist.

70-4 KINGSTON, ACN*; SPEISER, DI; University of South Carolina; *acnahm@gmail.com*

Snapping shrimp see through transparent armor

Snapping shrimp have specialized armor, termed the orbital hood, that covers their head and eyes. It has been proposed that orbital hoods protect the heads of snapping shrimp but impair their visual abilities. To explore the relationship between armor and vision in these animals, we examined the optical properties of the orbital hood, the morphology and physiology of the visual system, and the visually influenced behaviors of the big claw snapping shrimp *Alpheus heterochaelis*. We find that the orbital hoods of *A. heterochaelis* are made of transparent carapace that transmits 80-90% of incident light to their reflecting superposition eyes. Electroretinography (ERG) shows that the eyes of *A. heterochaelis* respond maximally to 500 nm light and demonstrate a flicker fusion frequency of > 40 Hz. Microspectrophotometry (MSP) reveals that the eyes of *A. heterochaelis* have two middle-wavelength sensitive (MWS) visual pigments that maximally absorb light at 501 and 519 nm. Behavioral trials using optomotor assays show that snapping shrimp demonstrate spatial vision with an angular resolution of ~ 8°. After discovering that *A. heterochaelis* has a functional visual system, we tested our hypothesis that the orbital hoods of snapping shrimp protect their heads from the shock waves produced by their snapping claws. To do so, we recorded shock waves produced by *A. heterochaelis* using pressure sensors mounted inside and outside of the orbital hoods of intact individuals. We compared these results to those from trials using individuals from which we removed orbital hoods. From these experiments, we discovered that orbital hoods decrease the magnitudes of shock waves by at least 40%. We conclude that the orbital hoods of snapping shrimp facilitate spatial vision and may protect their neural tissues from shock waves.

133-7 KIRKPATRICK, A*; KANATOUS, S; CROCKER, D; TRUMBLE, S; Baylor University, Colorado State University, Sonoma State University; *a_kirkpatrick@baylor.edu*

Fatty acids and Diving Development: Age class and sex differences in skeletal muscle fatty acid compositions the northern elephant seal Mirounga angustirostris

Fatty acid oxidation provides approximately 90% of energetic requirements in northern elephant seals (NES), yet little is known about the composition of their skeletal muscle fatty acids (FAs). Here, we report the skeletal muscle FA composition of NES within different age classes (adults {AD}, 1-year olds {1YR}, weaned pups {WP}) and sex. We analyzed 136 samples, spanning from 2012-2016, via GC-FID. A subset of 15 FAs, accounting for ~96% of FAs, were normalized and transformed. Saturated fatty acids (SFAs, ~65%) dominated muscle tissue in all age classes, monounsaturated fatty acids (MUFAs, ~19%) were the second most abundant and polyunsaturated fatty acids (PUFAs, ~11%) were the least abundant. Muscle tissue was predominantly composed of five FAs, C16:0, C16:1, C18:0, C18:1n9c and C20:2 (81% total FA). Multivariate analysis (MANOVA) of FA groups (SFA, MUFA, PUFA) indicated a significant effect of age class (F[4,248]= 14.40 p

136-6 KISHI, Y*; BRÜCKNER, A; THOMAS, IM; PARKER, J; California Institute of Technology, Pasadena, CA, Columbia University, New York, NY; *ykishi@caltech.edu*

Hox-logic of Rove Beetle Chemical Weaponry

In the rove beetle subfamily Aleocharinae (Coleoptera: Staphylinidae) symbiosis with ants (myrmecophily) has evolved independently dozens of times. The predisposition to evolve myrmecophily has been attributed to an abdominal defensive gland in free-living species that equips the beetles for entry and exploitation of ant colonies. In some symbiotic species, the gland has undergone further specialization to synthesize and secrete compounds that manipulate ant behavior. The tergal gland is therefore a substrate for selection that has likely facilitated the repeated emergence of myrmecophily in Aleocharinae. Despite being a pivotal structure for this remarkable convergence towards myrmecophily, the molecular architecture of the gland and its chemical evolvability are poorly understood. We exploited a free-living aleocharine, *Dalotia coriaria*, to ask how this evolutionary novelty arises developmentally. The gland consists of two exocrine cell types: epithelial secretory cells (termed D2) that form a reservoir into which fatty acid derivatives are secreted, and classical glandular units (termed D1), composed of a biosynthetic bulb and duct cell, which synthesize irritant benzoquinones. The benzoquinones are trafficked into the D2 reservoir where they dissolve, creating a defensive secretion. Using RNAi, we find that development of both D1 and D2 cell types requires the cooperative activity of the posterior Hox proteins abdominal A and Abdominal B. Strikingly, we find that the thoracic Hox protein Ultrabithorax is also involved: Ubx knockdown causes loss of benzoquinone-producing D1 cells. Hence, evolution of an unusual Hox code in aleocharines underlies the capacity of these beetles to manufacture defensive chemicals, and consequently, their convergent infiltration of ant colonies.

34-7 KITCHEN, SA*; BRUCKNER, A; KISHI, Y; MILLER, DR; NARAGON, T; WAGNER, J; PARKER, J; California Institute of Technology; *sak3097@caltech.edu*

Genomic insights into gland development of rove beetles

Rove beetles comprise the largest family in Metazoa with nearly 64,000 species. The vast radiation of rove beetles can be attributed in part to their shortened elytra that enhanced abdomen flexibility, thereby allowing occupation of diverse and novel habitats. A second key innovation was the evolution of a defensive tergal gland in the largest subfamily Aleocharinae that can discharge volatiles through abdomen flexing to deter predators. The development of this gland has been proposed as a primary preadaptation for social insect symbiosis and many lineages have convergently evolved into highly social, symbiotic organisms through repeated changes in morphology, glandular chemistry and behavior to assimilate into the complex societies of ants and termites. In this study we investigate the evolutionary "ground state" of aleocharine beetles through genomic, transcriptomic and chemical profiling. We present the near chromosome-level genome assembly of *Dalotia coriaria*, a new genetic model system, and draft genome assemblies of 15 other species. Genomic scans for conservation of genes, gene families and genomic architecture in tergal gland development were assessed within the higher Aleocharinae and the convergently-derived defensive glands of *Tribolium castaneum*. Genes previously characterized to be specific to the gland tissue and volatile production in *T. castaneum* were compared with differential expression of control and gland tissue, targeted RNA interference and quantification of gland volatiles with GC/MS in *D. coriaria*. We highlight common molecular processes underlying the evolution of the defensive gland in beetles and those specific to the aleocharines that were key to their diversification.

3-5 KLEINHEERENBRINK, M*; FRANCE, L A; TAYLOR, G K; Dept. of Zoology, University of Oxford, UK; *Marco.KleinHeerenbrink@zoo.ox.ac.uk*

Modelling the flight envelope for transition to an unpowered perching manoeuvre.

By gliding up to an elevated perch, a bird can convert some of its kinetic energy into potential energy. Besides storing energy that can be used again for take-off, this manoeuvre reduces the requirement for energetically-costly aerodynamic braking during the approach. The most efficient approach to the perch would limit the use of braking to trajectory corrections only. We investigated the constraints on the transition from powered flight to an unpowered perching manoeuvre by simulating constant-lift decelerating glide trajectories towards an elevated perch. We identified several physical constraints that limit the horizontal and vertical distance to the perch by which gliding must be initiated. The requirement to fly faster than the stall speed causes the minimum required vertical distance to increase for smaller horizontal distances. On the other hand, a larger vertical distance requires a steeper pull-up manoeuvre, which leads to two further limits constraining the maximum vertical distance to the perch: the maximum load that the wing can sustain, and the need to avoid an inverted approach. Together, these limits constrain the minimum horizontal distance that a bird needs to perform a successful perching manoeuvre. In an experimental setting, involving four Harris' hawks, we controlled the distance between perches and found that the behaviour of these birds matched the modelled limits: when the perch distance was large, the birds flew near to the floor, with a gliding approach to the perch; for short distances, the birds flew straight to the perch and instead performed a powered braking manoeuvre. As straight, level flight would in principle work for any perching distance, the observed flexibility in strategy demonstrates an implicit awareness of the underlying physical constraints.

2-1 KLEPAC, CN*; BARSHIS, DJ; Old Dominion University, Norfolk, VA; *cklep001@odu.edu*

Decreased thermal tolerance in corals from high-frequency variable environments

Coral bleaching events (i.e., dis-association between coral animals and their dinoflagellate photosymbionts) are increasing in frequency and severity, resulting in widespread losses in coral cover and an urgency to identify resilient populations. Recently, research has found stress-tolerant coral populations that are adapted to highly variable environments and possess greater bleaching resistance than corals from more moderately variable habitats. Using well-studied, environmentally variable backreef lagoons (Ofu Island, American Samoa), we evaluated the thermal tolerance scope of the massive coral *Porites lobata* following a reciprocal transplant experiment between a Moderately Variable (MV) and Highly Variable (HV) pool, as well as transplanting from a Low Variability (LV) pool into the HV pool. Transplanted and native samples were exposed to a controlled acute thermal stress throughout a two-year transplant period. Corals transplanted into the HV pool had reduced growth, decreased photosynthetic efficiency, and greater chlorophyll loss following acute heat stress compared to native back-transplants in their pool of origin. HV corals grew the most yet exhibited the greatest bleaching susceptibility compared to MV and LV natives. Surprisingly, MV native corals were resilient to acute thermal stress. In contrast to previous studies, there was a thermal anomaly in the region where Ofu's backreef thermal regime surpassed historical records – 2017 had up to 9.5 Degree Heating Weeks (DHW), 2016 and 2015 had up to 8 and 5 DHW, respectively (in comparison to ≤ 3 over the last 10 yrs). These results indicate the HV environment greatly exceeded historical variability and could be reaching a tipping point from enhancing coral stress tolerance to potentially overwhelming upper tolerance limits.

109-9 KLOMPEN, AML*; SANDERS, SM; CARTWRIGHT, P; University of Kansas, Lawrence, Thomas E. Starzl Transplantation Institute, University of Pittsburgh School of Medicine, Pittsburgh; *annaklompen@ku.edu*

Hazardous Hydroids of Hydractinia: Variation in venom expression and nematocyte distribution in functionally distinct tissues of a hydractiniid hydrozoan

The role of venom with respect to ecological interactions is an active area of research. For instance, varying ecological conditions can alter the composition and expression of venoms between populations and even within individuals. Some species compartmentalize venoms for specific purposes into distinct structures, such defensive and predatory venoms within the ducts of cone snails or varied venom expression in the competitive structures of sea anemones. Cnidarians (jellyfish, hydroids, corals, etc.) are the earliest diverging venomous animals and display extremely diverse life history characteristics. Yet, little is known about their venom composition with respect to biological or ecological roles. Hydractiniid hydrozoans are an ideal system to study influences of ecological function on venom composition due to their functionally specialized tissue types and complex life cycles. The hydractiniid *Hydractinia symbiolongicarpus* displays a division of labor among the polyps in a colony: gastrozooids (feeding, digestion), dactylozoids (defense, predation), and gonozooids (reproduction). How does venom composition vary between the functionally distinct tissues within *H. symbiolongicarpus*? Using existing RNA-seq data from the different polyp types, we characterized the putative venom composition and expression between these tissues. We also determined the nematocyte (stinging cell) distribution between each polyp. By comparing RNA-seq and nematocyte distribution data between functionally specific tissues of *H. symbiolongicarpus*, we show that different venom arsenals correlate with specific functions and hypothesize that some venoms may be nematocyte-type specific (an ongoing question in cnidarian biology).

39-4 KO, D*; HADDAD, A; LIN, H-T; Imperial College London; *dsk13@ic.ac.uk*

Visual Target Information Encoding Mechanisms in the Dragonfly

Dragonflies perform impressive aerobatics to catch prey in flight, using their acute vision to locate and track prey pre and post take-off. Dragonflies track their prey by keeping it above the dorsal fovea of their eye throughout a hunt. The amount of tracking error is known to be an effective predictor of hunt success. Due to the limited neural information bandwidth in the ventral nerve cord of the dragonfly, efficient encoding of relevant spatial and directional information of the prey is critical. A set of 16 visually responsive neurons called Target Selective Descending Neurons (TSDNs) have been shown to encode the direction of prey motion. However, the full extent of the receptive fields (edge to edge with high resolution) as well as the prey position encoding mechanisms in these neurons are not known. We introduce the full extent of TSDN receptive fields and their implications on the nature of coding of spatial and directional states of visual targets in the TSDNs. The complete receptive field data allow rigorous testing of different coding hypotheses and the construction of a model that incorporates position, direction and the classes of prey trajectories.

34-3 KOCOT, KM; The University of Alabama; *kmkocot@ua.edu*
Revolutionizing Biodiversity and Systematics Research on Aplacophora (Mollusca) and Training the Next Generation of Invertebrate Systematists
Aplacophora is an ecologically important and phylogenetically significant clade of worm-shaped marine molluscs. Basic questions about aplacophoran biodiversity and evolution, such as the number of species, evolutionary relationships, and ancestral states of key characters remain unanswered. The number of aplacophoran taxonomists, which has always been small, has declined in recent years. Meanwhile, known but undescribed species and specimens collected in environmental surveys that remain unidentified continue to grow in number. Specimen identification often requires the labor-intensive process of histology, but newer technologies such as micro-CT scanning and DNA barcoding could significantly accelerate this process. I will present on a new project aimed at dramatically accelerating the pace of the study of aplacophoran biodiversity and systematics while training the next generation of malacologists. Specimen identification will employ a novel workflow combining stereo light microscopy, micro-CT, and SEM of whole specimens, DNA barcoding, and compound light microscopy of permanent sclerite mounts - all from the same animal. Goals of this project include identification of thousands of specimens, description of >50 new species, characterization of the faunas of particularly diverse and understudied regions, monographs for select taxa in need of revision, and production of a reference DNA barcode library. Further, the first aplacophoran genomes will be sequenced, enabling target-capture phylogenomics. A well-resolved and broadly sampled phylogenetic framework will make possible a revised classification that accurately reflects the group's evolutionary history as well as ancestral state reconstruction of key traits for Aplacophora, Aculifera, and Mollusca as a whole.

78-3 KOEHL, MAR*; NGUYEN, H; FAUCI, L; University of California, Berkeley, Trinity University, Tulane University; *cnidaria@berkeley.edu*
Effects of Cell Morphology, Attachment to a Surface, and Colony Formation on the Hydrodynamic Performance of Choanoflagellates
Choanoflagellates, eukaryotes that are important predators on bacteria in aquatic ecosystems, share a common ancestor with sponges and are used as a model system to study the evolution of animals from protozoan ancestors. The choanoflagellate *Salpingoeca rosetta*, which has a complex life cycle that includes unicellular and multicellular stages, provides a model system to study within one species the functional consequences of: 1) different cell morphologies (swimming cell with a collar of prey-capturing microvilli surrounding a single flagellum; dispersal-stage cell with a slender body, long flagellum, and short collar), 2) being free-swimming vs. sessile (thecate cell attached to a surface), and 3) being a single cell vs. a multicellular colony. We used high-speed microvideography to measure swimming and feeding currents produced by different life stages, and computational fluid dynamics to study the effects of specific aspects of morphology on the fine-scale hydrodynamics of swimming and feeding. We found that a longer flagellum increases swimming speed, longer microvilli reduce speed, and cell shape only affects speed when the collar is very short. The flux of prey-carrying water into the collar capture zone is greater for swimming than sessile cells, but this advantage decreases with collar size. Stalk length has little effect on flux for sessile cells. Cells tethered to each other in colonies produce faster feeding currents and capture more prey per cell per time than do single cells, but there is a trade-off between feeding performance and predator avoidance because colonies produce larger hydrodynamic signals than do single cells.

140-5 KOLCHENKO, S*; ABDENNUR, N; LOE-MIE, Y; PLESSIER, F; SAUDEMONT, B; FRINTZENWANKER , J; LOWE, C; MIRNY, L; SPITZ, F; MARLOW, H; The University of Chicago and Institut Pasteur, MIT, Institut Pasteur, Institut Pasteur, Stanford University; *kolchenkosergey@gmail.com*
Evolution of Genome 3D organisation in Metazoa
We sought to find how spatial organisation allowed for evolution of increased complexity of gene regulation by comparing the genome 3D organization of species from different clades using chromosome conformation capture techniques. We developed a set of computational tools to identify features associated with TADs and compartments and showed that the characteristic features of loop-extrusion domains are far less prominent in protostomes (such as *Drosophila melanogaster*) than in vertebrates. Accordingly, the drosophila genome appears mostly folded in small compartments, reflecting the nature of the underlying chromatin and transcriptional activity. In contrast, the domains we observed in the hemichordate *S. kowaleskii* and in the lancelet showed features characteristic of loop-extrusion and their boundaries showed significant and strong enrichment for CTCF motifs, indicating that they correspond predominantly to bona fide TADs. Furthermore, by using single-cell RNA-Seq data, we show that in hemichordates, genes located in TADs are more likely co-regulated than genes separated by a TAD boundary. We did not observe such domains in cnidarians, who branched before the evolution of CTCF, or tunicates, such as *Ciona intestinalis*, who has a modified CTCF gene, suggesting that they use different systems for gene regulation. Altogether, our studies underline that the evolution of the 3D genome, and in particular the innovation represented by cohesin-based and CTCF-delimited TADs, may have fueled regulatory innovation by extending the possible genomic space available to store gene regulatory elements.

89-4 KOLLATH, D/R*; TEIXEIRA, M/M; MILLER, K/J; BRIDGET , B/M; FUNKE, A; Pathogen and Microbiome, Northern Arizona University , University of Brasília Campus Universitário Darcy Ribeiro, Asa Norte, Brasília-DF Brazil, Imaging and Histology Core Facility, Northern Arizona University, Flagstaff, AZ, USA; *drk87@nau.edu*
Investigating the Role of Animal Burrows on the Ecology and Distribution of Coccidioides spp. in Arizona Soils.
The lack of knowledge regarding the ecology of Coccidioides spp. makes both modeling the potential for disease outbreaks and predicting the distribution of the organism in the environment challenging. No single ecological parameter explains the biogeography of the pathogen and the desert mammal association hypothesis has some support, but should be reexamined using modern molecular techniques. Therefore, the ecology and biogeography of Coccidioides spp. in Arizona was assessed by using molecular tools to analyze soils associated with animal activity (i.e. burrows). Soils were collected from locations outside of the established endemic regions to better understand the ecological niche of the organism in this state. Our central hypothesis is that soils taken from within animal burrows will have a higher abundance of Coccidioides spp. when compared to soils not directly associated with animal burrows. Results show that there is a positive relationship with Coccidioides spp. and animal burrows. The organism was detected in two locations in Northern Arizona at sites that are not known previously to harbor the fungus. Moreover, this fungus is able to grow on keratinized tissues (i.e. horse hair). These results provide additional evidence that there is a relationship between Coccidioides spp. and desert animals, which sheds new light on Coccidioides' ecological niche. These results also provide evidence that the geographic range of the organism may be larger than previously thought, and the concept of endemicity should be reevaluated for Coccidioides.

73-1 KOLMANN, MA*; HUGHES, LC; EVANS, K; HUIE, JM; ORTI, G; HERNANDEZ, LP; George Washington University, Brown University, University of Washington; *mkolmann@gmail.com*
Carnivorous grazers? How to build scale-feeding and fin-feeding fishes from less egregious relatives
The tropics are home to some of the most nuanced examples of ecological specialization: from frogs that raise their young in puddles formed on only certain plants (phytotelmata), to fish species that subsist by parasitizing close relatives, some actively mimicking their sister taxa. The tropics are rife with a myriad of animals that parasitize, clean, compete or prey on co-occurring taxa, be they confamilials, conspecifics, or organisms not closely related at all. What, if anything, do these taxa share in common? This is especially clear in Neotropical freshwater fishes, where a notable number of scale-feeding, fin-feeding, and mucus-feeding taxa occur (and some cleaners too). The best examples of these sorts of behaviors occur in the characiform fishes: tetras, payara, tambaqui, and others - otophysan fishes which comprise the vast majority of freshwater fish diversity worldwide. We examined feeding and body shape morphology among diverse Neotropical characiform ectoparasites with micro-computed tomography scanning in order to answer whether there are any traits in particular that are shared among these particularly belligerent fishes. We find that few characters distinguish ectoparasitic fishes from their confamilials - i.e., it appears rather easy to make an ectoparasite in sheep's clothing. However, robust teeth and elongate lower jaws may be important for feeding performance, perhaps for leveraging scales and mucus from prey. Some manner of ectoparasitism has evolved at the family-level at least eight times in characiforms, and some four times within characoids alone. We discuss whether these strategies constitute evolutionary ‘dead ends' and why such specialized niches may not beget specialized morphologies.

85-1 KONOW, N*; PANESSITI, C; SCHWARZ, D; BOUVIER, C; MARBELT-RODRIGUEZ, C; HEISS, E; ROSS, CF; RULL, M; UMass Lowell, U. Jena, U. Jena, U. Chicago; *Nicolai_konow@uml.edu*
Food processing across the fish-tetrapod split
Food processing, or cyclic application of dentition-clad surfaces to ingested food, is rhythmic among mammals (grand mean CV; Coefficient of Variation = 15%) and basal bony fishes (25%) and less so among lepidosaurs (lizards and their allies; 53%). This phylogenetic shift in rhythmicity from aquatic-feeding anamniotes to terrestrial amniotes is not readily explained by variation in the proprioceptive capabilities of the jaw closers. However, the shift might be influenced by changes in fluid properties (water to air) as vertebrates move from aquatic to terrestrial chewing. We examine variation in chewing rhythmicity across the fish-tetrapod transition using data from basal actinopterygians (*Polypterus sp.*), lungfishes (*Neoceratodus fosterii*; *Protopterus annectens*), and salamanders (*Ambystoma mexicanum*, *Siren intermedia*, *Amphiuma means*, *Plethodon sp.*, *Ichthyosaura alpestris*, and *Triturus carnifex*). Among ancestral gnathostomes, processing rhythmicity rivals that of mammals (*Polypterus*, CV = 17%) and rhythmicity is generally high in aquatic-feeding sarcopterygians (*Protopterus*, 14%; *Neoceratodus*, 34%). The grand average CV for processing rhythmicity among lissamphibians (28%) is not statistically significantly different from that of other anamniote chewers. However, CV is consistently higher for terrestrialized than aquatic salamander morphs. These data suggest an ancestral state for gnathostomes of high processing rhythmicity, which is somewhat perturbed by transitions to terrestriality. However, to explain the uniquely arrhythmic chewing behavior of lepidosaurs we might need to invoke behavioral attributes, such as inertial food handling.

28-8 KORNEV, K*; APRELEV, P; BRASOVS, A; ADLER, P; BEARD, E; Clemson University; *kkornev@clemson.edu*
Probing viscosity of insect blood at different spatial and time scales
When studying insect biomechanics, it is crucial to understand the materials properties of blood at different time and length scales. Insect blood is a suspension of adherent and non-adherent micron-sized cells suspended in plasma. Even though at the macro-scale the suspension may behave as a single-phase liquid, it has been a long-standing challenge to measure its materials properties at the micro- and nano-scales, where the effects of cells can be significant. Magnetic Rotational Spectroscopy allows one to probe these multi-scale rheological properties in real time. We quantitatively study nucleation of cell aggregates that occurs within fractions of a second. Using larvae of Manduca sexta, we discovered that clot nucleation is a two-step process whereby cell aggregation is the time-limiting step followed by rigidification of the aggregate. Clot nucleation and transformation of viscous blood into a visco-elastic aggregate happens in a few minutes, which is hundreds of times faster than wound plugging and scab formation. In contrast, hemolymph of adult lepidopterans is a Newtonian viscous fluid. Hemolymph of Monarch and Painted lady butterflies and Manduca sexta moth still shows surprises: a threefold difference in viscosity between these species suggests an important physiological implication of hemolymph constituents most likely related to the flight fuel. 1. Aprelev, P., Bruce, T.F., Beard, C.E., Adler, P.H., Kornev, K.G. Nucleation and formation of a primary clot in insect blood, Scientific Reports, 9, 3451(2019)

54-2 KOVACS, JL*; WERREN, J; Spelman College, University of Rochester; *jkovacs@spelman.edu*
Horizontal Gene Transfer as a Mechanism for Convergent Evolution in Arthropods
"How do organisms acquire new traits?" is a central question in evolutionary biology. We know that new traits can arise a number ways including mutations, gene duplications, and chromosomal inversions. We also know that prokaryotes, such as bacteria, can acquire traits from other bacteria or from their environment through a process known as horizontal gene transfer (HGT). These horizontally transferred genes can allow their new host to rapidly adapt to their environment. Until recently, it was thought the HGT happened only in prokaryotes, but multiple cases of functional HGT have been documented in a wide range of eukaryotes, including a variety of arthropod species. We currently have a very limited understanding of how widespread HGT is in eukaryotes and how it has contributed to the evolution and diversification of eukaryotes. The goal of this project is to identify, validate and characterize HGTs in fifteen species of blood-feeding and herbivorous arthropods. We are particularly interested in the role that HGTs play in allowing organisms to exploit new environments, therefore we will pay special attention to HGTs that are shared across multiple species that share a similar ecological niche, but are absent in more closely related arthropods that have a different feeding behavior. We hypothesize that HGT has repeatedly allowed for the independent acquisition of similar novel phenotypic traits in multiple distantly related arthropod species and has allowed for niche invasion and novel resource exploitation in these species. This work will test the prediction that HGTs will be shared by multiple niche-sharing species, either blood-feeders or herbivores, while being absent from more closely relates, but non-niche sharing species.

17-5 KOZMA, MT*; NGO-VU, H; SENATORE, A; BOBKOV, Y; ACHE, BW; DERBY, CD; Georgia State Univ., Univ. of Toronto, Mississauga, Whitney Lab, Univ. of Florida; *mtottempudi1@gsu.edu*

Single Cell Transcriptomics Reveals Expression Patterns of Chemoreceptor Genes in Olfactory Receptor Neurons of the Caribbean Spiny Lobster, Panulirus argus

Crustaceans express several classes of putative chemoreceptor proteins. These include variant ionotropic glutamate receptors (IRs) that have co-receptor IRs and tuning IRs that confer response specificity by forming heterotetrameric ion channels, Transient Receptor Potential (TRP) channels, Gustatory Receptors, and possibly others. The Caribbean spiny lobster, *Panulirus argus*, expresses over 200 IRs, 15 TRP channels from all TRP subfamilies, and 1 GR. However, the combinatorial expression pattern of these proteins in single chemoreceptor cells is not known for this or any crustacean species, limiting our understanding of how crustacean chemoreceptor systems encode chemical quality. We generated and analyzed seven single cell transcriptomes to provide a first view of the expression patterns of chemoreceptor proteins in olfactory receptor neurons (ORNs) in spiny lobsters. We found that all seven single-ORN transcriptomes contained two co-receptor IRs (IR25a, IR93a) and one TRP channel (TRPA1). In addition, single ORNs expressed 1–2 tuning IRs and also TRP channels belonging to subfamilies TRPA, TRPM, and TRPC. Tuning IRs included arthropod-conserved IRs, IR40a and IR75, as well as species-specific IRs. We did not detect two other co-receptor IRs, IR8a or IR76b, in the single-ORN transcriptomes despite their presence in the transcriptome of the olfactory organ. Our results yield an initial view of combinatorial expression of co-receptor IRs, tuning IRs, and TRP channels in ORNs from this decapod crustacean, where ORNs may express different subsets of receptor molecules compared to other types of chemoreceptor neurons.

80-3 KRAUSE, JS*; REID, AMA; PEREZ, JH; BISHOP, V; RAMENOFSKY, M; WINGFIELD, JC; MEDDLE, SL; UN Reno and UC Davis, U. Edinburgh, Roslin Institute, Roslin Institute, UC Davis; *jskrause@unr.edu*

The reduction in negative feedback sensitivity underlies seasonal changes in corticosterone in free-living migrant white-crowned sparrows

The CORT-Flexibility Hypothesis proposes that seasonal changes in corticosterone can fine tune the onset of breeding. Circulating corticosterone is mediated by the hypothalamic pituitary adrenal (HPA) axis in response to environmental challenges. Corticosterone is regulated by negative feedback through mineralocorticoid (MR) and glucocorticoid (GR) receptors, although glucocorticoid levels that reach the receptors are regulated by 11 -Hydroxysteroid dehydrogenase (11 HSD1) which reactivates and 11 HSD2 which deactivates the hormone. We sampled plasma corticosterone in free-living male and female migratory white-crowned sparrows (*Zonotrichia leucophrys gambelli*) across their annual cycle and collected tissues during breeding, pre-basic molt, and winter stages to quantify gene expression in the hippocampus, hypothalamus, pituitary, and adrenal gland. Peak corticosterone production occurred during the territoriality and egg laying stages of the annual cycle. GR and MR mRNA expression were downregulated during breeding compared to winter in the hippocampus (not MR), hypothalamus, pituitary, and adrenal gland (not GR). 11 HSD2 mRNA was higher during breeding compared to winter in all tissues except the adrenal gland, and was the only gene to differ between sexes during breeding. While 11 HSD1 mRNA was unaffected by life history stage in any tissue measured. We found no change in mRNA for cholesterol esterase, side chain cleavage enzyme, or steroid acute regulatory protein in the adrenal gland. These data suggest that the seasonal peak in corticosterone is mediated through reductions in negative feedback sensitivity at multiple levels within the HPA axis.

130-3 KRIDER, L; HALSEY, L; YAP, KN; WILLIAMS, TD*; Simon Fraser University, Burnaby, University of Roehampton, UK; *tdwillia@sfu.ca*

Humans Get Fat on Fat Diets, Why Don't Birds?

Obesity is a major issue in modern human societies, in part linked to diet. Humans consuming more calories through eating highly-processed foods or high fat diets gain weight. Although some birds show marked seasonal fluctuations in body (fat) mass, e.g. migrants, many birds appear to tightly regulate body mass and don't get fat. Yet studies on the underlying mechanisms of mass regulation in these non-migrant birds are scarce. We attempted to make captive zebra finches fat by providing them with a high fat diet ad lib for 3 weeks. Birds consumed the high-fat food, and they had elevated plasma triglyceride levels, but there was no associated change in body mass. Birds had mean plasma triglyceride levels ~6-8 mmol/l but three apparently-healthy individuals had triglyceride levels > 60 mmol/l perhaps indicating an interesting "high-fat" phenotype. Body mass was highly variable among individuals, even controlling for structural size, and was highly repeatable at all stages of the experiment. However, birds showed little diurnal variation in body mass, which is common in free-living birds. The only major perturbation of body mass occurred when all birds were blood sampled (-3%), but individual birds returned to pre-sampling mass within 4-5 days, with high repeatability – again suggesting tight regulation of body mass. Zebra finches did show a significant reduction in body mass when exposed to visual and audio cues from a model barn owl – suggesting they retain the potential for 'strategic' regulation of mass in relation to certain cues (here a predator). Despite their unnatural habitat captive zebra finches might provide an interesting model to explore mechanisms that prevent some birds from getting fat.

56-4 KRIEFALL, NG*; MATZ, MV; KANKE, M; DAVIES, SW; Boston University, UT Austin, Cornell University; *nicfall@bu.edu*

Symbiotic partners diverge across reef environments in a panmictic coral population

Corals from more variable environments tend to fare better under thermal stress when compared to their counterparts from more stable environments. Marine environments exhibiting more or less thermal variability are ubiquitous and even reef zones within the same reef can display divergent thermal profiles. These reef zones offer an opportunity to investigate the role that thermal variability plays in coral resilience and may shed light on how best to manage reefs under climate change. Studies have demonstrated that multiple members of the coral holobiont (the coral host and its associated microorganisms) play a role in a coral's capacity to cope with reef zone differences, however, few studies have contrasted more than two holobiont partners across these environments. Here, we profiled the genetic structure of the coral host, *Acropora hyacinthus*, along with the community compositions of its resident algal symbionts and microbiome from three paired inshore (more variable) and offshore (more stable) reef zones in French Polynesia. 2b-RAD sequencing determined that this broadcast spawning coral exhibited complete panmixia across all reefs regardless of environmental characteristics. In contrast, using ITS2 metabarcoding, we consistently found that algal symbiont communities within offshore corals had higher alpha diversity. In addition, 16S metabarcoding revealed subtle differences in microbiome taxa between reef zones. Our results from investigating this tripartite symbiosis support previous findings suggesting that microbial partners play a role in the ability of their coral hosts to cope with environmental variation. As oceans continue to warm, contrasting how different holobiont partners vary across reef environments may help illuminate coral resilience in a changing world.

S6-8 KRISHNAMOORTHY, K; CAPUANO, F; GURKA, R*; BALARAS, E; Coastal Carolina University, University of Naples Federico II, George Washington University; *francesco.capuano@unina.it*

Numerical and experimental study of owls flapping flight

The fluid dynamics of the flapping flight of owls is studied experimentally and numerically. We analyzed a great horned owl, a tawny owl, and a Harris hawk. The latter was chosen to carry out a comparative analysis with the similarly-sized great horned owl. We conducted high-speed, long-duration time-resolved PIV experiments in an open wind tunnel. A perch-to-perch flight style was chosen, and multiple flights were performed for all the birds. High-speed cameras synchronized with the PIV were utilized to capture the kinematics of the birds from different views during flight. The kinematic images display a similar flight path for the three birds, while a comparison of the wake characteristics shows similarities between the two owls and a distinct difference for the hawk in terms of wake flow patterns and turbulence features (intensity and kinetic energy). In conjunction to the experiments, we performed direct numerical simulations (DNS) of the flow generated by an owl in the flapping flight. The wing geometry was extracted from the planform image of the owl wing and a triangulated 3D model was reconstructed. The kinematics were extracted from the trajectories of a set of markers placed along the wing span, which were recorded during the wind tunnel flight. The motion of the markers was transferred to the triangulated surface model by means of an image-registration technique based on the large deformation diffeomorphic metric mapping (LDDMM) framework, allowing alignment of the surface meshes at various phases of the flapping cycle. The derived position and velocity of each point were used as a boundary condition for the computations. The latter were conducted utilizing an immersed boundary (IB) method, which is a cost/efficient approach to conduct DNS with large boundary displacements.

S6-7 KRISHNAN, K; BEN-GIDA, H; GUGLIELMO, CG; GURKA, R*; CCU, Technion, UWO; *rgurka@coastal.edu*

Wake Flow Mechanisms and Aerodynamic Forces of Owls During Flapping Flight

The mechanisms associated with the owls' silent flight have been an active scientific research for decades as an inspiration to find solutions for noise reduction applications. Aerodynamic noise generated during flight is associated with the fluid-structure interaction phenomena and the turbulent nature of the flow. When turbulent airflow past the owl wing it is constantly interfered with the wing. During flapping, this interaction results in a more complex three-dimensional unsteady wake. The formed wake is shed downstream and carries the history of the flow affected by the bird. The interaction between the turbulent wake and the wing motion governs the aerodynamic forces acting on the owl and attenuating the noise at the interface region. Understanding the downstream wake-flow dynamics of owl flight can possibly elucidate the aerodynamic mechanisms employed by owls during flight and provide insight to the reduction of the aeroacoustics noise. We focus on the role of turbulence as a noise source and its impact on the aerodynamic performances of owl during flapping flight. We chose three owl species: boobook owl, great horned owl and Tawney owl. The owls were freely flown in a climatic wind tunnel. The wake flow field was measured using long duration high-speed PIV and the owls' kinematics were characterized using high-speed imaging, simultaneously. Large lift and drag variations over the wingbeat cycle were observed, demonstrating the unsteady effects of the flow on lift. The owls' wakes were populated by relatively small turbulence scales. Turbulent energy budgets at the wake depicted high levels of dissipation compared to turbulent production. By estimating the vorticity-strain relations at the wake, we have calculated the pressure gradients at the wake which are proportional to the aerodynamic noise. These appeared to be suppressed, indicating a passive control mechanisms through turbulence dissipation.

111-5 KRUPPERT, S*; CHU, F; STEWART, MC; SCHMITZ, L; SUMMERS, AP; Friday Harbor Laboratories, University of Washington, University of Washington, Scripps College, Claremont, Scripps College, Claremont; *skrupp@uw.edu*

En Garde! The poachers' body armor is no show-off but a heavy defensive trait.

Many vertebrates are armored over part or all of their body. The armor can serve several functional roles including defense/protection, offense, visual display, and communication of capability. Different roles imply different tradeoffs, for example defensive armor often trades resistance to attack for maneuverability. The poachers (Agonidae), 47 species of Scorpaeniform fishes, are a useful system for understanding the evolution and function of armor due to their high variety in extent of armoring. We report on an assessment of the amount of mineral in the armor compared to endoskeleton in a diversity of poachers, and an assessment of the damage type in armor across a growth series of one species of poacher. Using publically available CT scan data from 27 species from 16 of 21 genera of poachers we compared the armor to skeletal mineralization for a body region starting at the posterior end of the (first) dorsal fin going two times the body depth. The average material density (a measure of mineralization) of the armor in comparison to the skeleton ranged from 0.77 to 1.17, but the more impressive data is in the total mineralization (volume * average density). In some small, smooth scaled species, like *Aspidophoroides olrikii*, there was 10 times the material expenditure in the armor as in the endoskeleton. With 34 *Agonopsis vulsa* we carefully categorized the extent and type of damage to each of 35+ scales in the eight rows along the body. The ventral rows begin to show abrasive damage along the entire length of the fish. Impact damage to head and tail scales gets more severe and occurs at higher rates with age, suggesting the armor is not just for show.

12-6 KUHN, BF*; SALESA, MJ; MAURICIO, A; ARGANT, A; RANDOPH-QUINNEY, P; KGASI, L; GOMMERY, D; University of Johannesburg, South Africa, Departamento de Paleobiología, Museo Nacional de Ciencias Naturales-CSIC, Madrid, Spain, Aix Marseille Univ, LAMPEA, Aix-en-Provence, France , School of Forensic and Applied Sciences, University of Central Lancanshire, Preston, UK, Hope Research Unit, Plio-Pleistocene Palaeontology Section, Ditsong National Museum of Natural History, Pretoria, South Africa , Hope Research Unit, Plio-Pleistocene Palaeontology Section, Ditsong National Museum of Natural History, Pretoria, South Africa and Palaeo-Research Institute, University of Johannesburg, South Africa and Sorbonne Université, Paris, France ; *kuhnbf@gmail.com*

Evidence for an African Cave Lion (Panthera sp): Multiple Panthera individuals from Bridge Cave, Bolt's Farm, South Africa

Recent excavations at the Bridge Cave location within the Bolt's Farm system have yielded an unprecedented number of Pantherine fossils. To date in excess of 1600 fossils have been recovered from the constrained deposit which measures 1.5 meters across, half a meter high and half a meter deep. Of these fossils, over 600 have been attributed to Panthera. With examples of nearly every bone in the body recovered, and multiples of many elements, we can say with confidence that we have at least eight individuals represented in this assemblage. These individuals are made up of six adult male African lion (Panthera leo) size individuals, a seventh individual noticeably larger than these and a very young juvenile. Taphonomy suggests that a latrine was present inside the cave, lending support for the theory that these ‘lions' were in fact denning inside of the cave. Other recovered fauna includes mega fauna such as Equus capensis, Phacochoerus modestus, Metridiochoerus andrewsi and class five bovid remains. The presence of Phacochoerus modestus as well as Metridiochoerus andrewsi indicates an age of approximately 1.8 million years.

32-8 KUNKEL, E L*; DALE, A S; FULLER, N W; MCGUIRE, L P; Texas Tech University, Lubbock, TX; *Emma.Kunkel@ttu.edu*
Partial Migration in Mexican free-tailed Bats: Ecology and Bioenergetics of Winter Residents
Migration evolves when the benefits of migrating outweigh the costs of remaining sedentary. However, migration is a characteristic of individuals and the costs and benefits of migration can vary among individuals. Such variation can result in partial migration where some individuals migrate and others forego migration. Previous investigations of partial migration have focused on homeothermic species where costs of foregoing migration are driven primarily by energy availability. However, heterothermic species can reduce energy expenditure in response to varying energy availability. We investigated the energetic strategies of Mexican free-tailed bats overwintering in Texas. We hypothesized overwintering bats would exhibit flexibility in maintaining energy balance by maximizing energy intake via foraging on warmer nights and reducing energy expenditure by decreasing activity and using torpor while inactive, with multi-day torpor bouts during longer periods of harsh weather. We regularly captured bats between September 2018-May 2019 and measured plasma triglyceride concentration of 137 individuals and deployed an acoustic monitor to continuously record bat activity. In February 2019 we attached temperature-sensitive radiotransmitters to 30 bats to continuously record their skin temperature. Bat activity was strongly affected by weather, with reduced activity on colder nights. Bats regularly used torpor during the day and were able to extend torpor bouts over multiple days during extended periods of harsh weather. Surprisingly, plasma triglyceride levels were extremely low during all winter capture events indicating bats rarely forage during winter. These sub-tropical mammals withstand winter via regular torpor use but despite being active do not capitalize on winter foraging opportunities.

134-5 LABONTE, D; Imperial College London; *d.labonte@imperial.ac.uk*
Dynamic biological adhesion: mechanisms for controlling attachment during locomotion
The rapid control of surface attachment is a key feature of natural adhesive systems used for locomotion, and a property highly desirable for man-made adhesives. Here, we describe the challenges of adhesion control and the timescales involved across diverse biological attachment systems and different adhesive mechanisms. The most widespread control principle for dynamic surface attachment in climbing animals is that adhesion is `shear-sensitive' (directional): pulling adhesive pads towards the body results in strong attachment, whereas pushing them away from it leads to easy detachment, providing a rapid mechanical `switch'. Shear-sensitivity is based on changes of contact area and adhesive strength, which in turn arise from non-adhesive default positions, the mechanics of peeling, pad sliding, and the targeted storage and controlled release of elastic strain energy. The control of adhesion via shear forces is deeply integrated with the climbing animals' anatomy and locomotion, and involves both active neuromuscular control, and rapid passive responses of sophisticated mechanical systems. The resulting dynamic adhesive systems are robust, reliable, versatile and nevertheless remarkably simple.

135-6 LAD, SE*; CORTESE, SA; DANISON, AD; RAVOSA, MJ; University of Notre Dame, Notre Dame, IN, College of Wooster, Wooster, OH; *slad@nd.edu*
Bone Remodeling and Cyclical Loading in the Maxilla of White Rabbits (Oryctolagus cuniculus)
Processing mechanically challenging (e.g., tough or stiff) foods alters feeding behaviors in mammals, requiring larger bite forces or prolonged mastication. The bony response to high bite forces in the mammalian skull is well known, but osteogenesis due to protracted chewing (i.e., cyclical loading) is more poorly understood. Prior studies indicate greater bone formation in mandibles of rabbits raised on mechanically challenging foods, and a stronger link between bone remodeling and cyclical loading vs. high-magnitude strains. Here we assess the relationship between cyclical loading and remodeling, the repair of microdamage due to mechanical deformation and fatigue loading. Ten male white rabbits (*Oryctolagus cuniculus*) were obtained at weaning (4 weeks) and raised on one of two diets until mature (52 weeks). Five subjects ate pellets (E=29Mpa, R=1031Jm^{-2}), and the other five processed pellets and hay (E=3336Mpa, R=2760Jm^{-2}). Mastication of hay results in higher chewing investment (475 vs. 161 chews/g) and prolonged chewing duration (568 vs. 173 sec/g). Remodeling was measured as osteon population density (OPD) and percent Haversian bone (%HAV) in 100µm coronal sections of left maxillae between P2 and P3. An outlier was excluded from analysis due to sectioning error. Mean OPD and %HAV were greater in the hay group, but Mann-Whitney U tests revealed no significant difference between treatments (P=0.111, both). This finding suggests that elevated cyclical loading does not result in greater remodeling in rabbit maxillae. Future analyses will examine additional subjects as well as other cranial sites to more fully characterize mechanisms of adaptive plasticity in bone quantity and quality.

S11-6 LADAGE, LD; Penn State Altoona; *ldl18@psu.edu*
Reptiles: an evolutionarily important link in comparative cognition and neurobiology
In the 1960's, MacLean's concept of the triune brain and its coevolution with cognitive abilities embedded itself into the fabric of psychology and the minds of the general public. For decades, it was assumed that reptiles possessed little to no complex cognitive abilities, with a brain that subserved basic survival functions. While the triune brain model has since been discredited, the bias has been subtly perpetuated, despite reptiles engaging in a diverse repertoire of behaviors including extraordinary navigational feats, social learning, and higher cognitive learning abilities. To determine if these behaviors are indeed cognitively-based requires an ecologically-relevant testing paradigm; correlating these behaviors with the neural architecture typically associated with cognitive abilities lends further support that these behaviors have a cognitive basis. In fact, recent studies have demonstrated that many of the reptilian behaviors that appear to require complex cognitive abilities are associated with areas of the brain that are homologous to those underlying complex cognitive processing in mammals (e.g., the hippocampus). Thus, reptiles represent a relatively understudied yet evolutionarily important group in comparative cognition. Examining the cognitive basis of reptilian behaviors as well as the neural underpinnings underlying those behaviors illuminates the evolutionary trajectory of cognition and the functional and structural similarities and dissimilarities between the reptilian and mammalian brain.

S2-3 LANCASTER, LT*; MCCAW, B; ARESHI, S; LEONARD, A; MOORE, B; STEVENSON, TJ; University of Aberdeen, Aberdeen, United Kingdom, University of Glasgow, Glasgow, United Kingdom; *lesleylancaster@abdn.ac.uk*

Epigenetic effects on thermal tolerance and resource use shifts in insects, with implications for range shift potential and life history syndromes

Many species are shifting and expanding their geographic ranges under anthropogenic environmental change. These expanding species include native species which are taking advantage of warming climates to settle in previously inhospitable areas beyond their previous range margins, and invasive pest species which are rapidly colonizing novel industrial / agricultural landscapes. Many studies now show that as these colonizing species shift to new regions, they also adapt very rapidly to novel climate and resource conditions encountered there. Such rapid adaptation presents somewhat of an evolutionary paradox, as genetic variation is often depleted during colonization events. In this talk I will present recent work done by my group on how epigenetic mechanisms contribute to rapid life history transitions, resource use shifts, and rapid thermal adaptations within two insect study systems, the seed beetle *Callosobruchus maculatus* (an expanding global pest on stored legumes), and the damselfly *Ischnura elegans* (which is rapidly expanding northward its native range in Europe under warming climates). The presented studies explore the role of DNA methylation in rapid adaptation to novel niches, but also highlight a central role of epigenetic mechanisms in shaping life history syndromes. The results are discussed in light of wider concepts of niche conservatism and life history theory.

27-5 LANZA, AR*; SEAVER, EC; Whitney Laboratory for Marine Bioscience, University of Florida; *alexislanza@gmail.com*

Activin/Nodal signaling is required for establishing the dorsal-ventral axis in Capitella teleta

TGF-beta superfamily signaling regulates a variety of developmental processes and has a conserved role in patterning the dorsal-ventral body axis. Within this signaling family, there are two distinct branches: the Activin/Nodal pathway and the BMP pathway. The spiralians are a large bilaterian clade that exhibit enormous body plan diversity. Members of this superclade share a highly stereotypic early development program called spiral cleavage, and signals emanating from single cells during early cleavages are critical for patterning the dorsal-ventral body axis. Studies in the mollusks *Crassostrea gigas* and *Tritia obsolete*, as well as the annelid *Helobdella robusta* have suggested the BMP pathway plays a crucial role in dorsal-ventral axis patterning. However, previous pharmacological inhibition studies in the annelid *Capitella teleta* suggests that signaling via the ALK4/5/7 receptor, an Activin/Nodal pathway receptor, patterns the dorsal-ventral axis. In this study, we further determine the role of the Activin/Nodal pathway as it functions in *C. teleta* axis patterning. Antisense morpholino oligonucleotides were designed to target *Ct-Smad2/3* and *Ct-Smad1/5/8*, receptor signal transducers specific to the Activin/Nodal and BMP pathways, respectively. Morphants were raised to larval stages and scored for phenotypic anomalies in body axes formation. Our findings confirm that axial patterning in *C. teleta* occurs at the 16 cell stage, 1-2 cleavage divisions before their spiralian counter parts, the mollusks, and utilizes the Activin/Nodal branch of the TGF-beta superfamily, but not the BMP pathway. Furthermore, these findings highlight an important molecular difference in the induction of axes between annelids and mollusks.

69-5 LANE, S/J*; EMMERSON, M/G; VANDIEST, I/J; HUCUL, C; BECK, M/L; DAVIES, S; GILBERT, E/R; SEWALL, K/B; Virginia Tech, Rivier University, Quinnipiac University; *samjl89@vt.edu*

Urbanization lowers hippocampal glucocorticoid receptor expression but not clearance of glucocorticoids in male Song Sparrows.

Individuals in urban habitats experience frequent disturbances and are expected to respond efficiently and recover quickly from challenges to persist in these habitats. The glucocorticoid (GC) stress response is a physiological response to a stressor during which GC concentration increases in order to activate behavioral and physiological mechanisms to recover homeostasis. Differences in the duration of GC secretion are modulated by the efficiency of negative feedback mechanisms, which is achieved primarily through the binding of glucocorticoid receptors (GRs) in the hippocampus by GC's. Efficient termination of the GC stress response could protect birds in urban habitats from chronic GC exposure. We investigated if male song sparrows (*Melospiza melodia*) in urban habitats show more efficient negative feedback of the GC stress response than their rural counterparts. Song sparrows from each habitat were exposed to restraint stress to increase corticosterone (CORT), the primary avian GC, then injected with either saline or a synthetic GC (dexamethasone, DEX), to induce a negative feedback response. Additionally, we quantified GR mRNA in the hippocampus using qPCR in a separate cohort of birds. Our results show that DEX suppressed CORT concentration below that of saline, but no habitat differences in response to DEX were detected. Urban song sparrows did have lower hippocampal mRNA levels of GR than rural song sparrows. Urbanization therefore does not affect the GC stress response, but can cause structural changes in the hippocampus, the functional effects of which remain to be elucidated.

84-6 LAPSANSKY, AB*; TOBALSKE, BW; University of Montana; *anthony.lapsansky@umontana.edu*

The biomechanics of multi-functional wings in diving birds

While water and air are fundamentally different media, diverse species locomote effectively in both. As a prominent example, roughly 40 species of birds across five extant clades have co-opted their wings for use in underwater propulsion, here termed "aquatic flight", while retaining their aerial flight. During aquatic flight, these species flex the wrist and elbow joints of their wings, substantially reducing the effective span and area of their wings relative to in aerial flight. To elucidate the function of this behavior, we investigated the aero- and hydrodynamic performance of the flexed and extended wing postures on pairs of wings from ten common murres (*Uria aalge*). We used a propeller model to emulate flapping in air and water and a wind tunnel to emulate gliding. We hypothesized that the flexed posture would produce greater ratios of vertical-to-horizontal force (an efficiency metric) across all conditions, but that the total vertical force produced by this posture would be insufficient for weight support. During emulated gliding, flexed wings did achieve greater ratios of vertical-to-horizontal force when all angles of attack (0-60 deg) were considered. However, during emulated flapping, extended wings achieved greater ratios of vertical-to-horizontal force and greater coefficients of vertical force at both aerial and aquatic Reynolds numbers. Extended wings produced 1.5-6X more vertical force than flexed wings, but even extended wings were insufficient for weight support -- consistent with the poor slow-flight performance of murres. It is therefore unclear why birds use a flexed wing during flapping of aquatic flight. Perhaps steady-state models fail to capture the performance of the flexed-wing posture or the use of a flexed wing for aquatic flight is compulsory due to limitations on factors outside of propulsor shape (e.g. structural or muscular constraints). (NSF IOS 1838688).

82-5 LARK, R; SHARABI, L; LEVY, O*; Tel Aviv University, Israel; *levyofi@gmail.com*

The use of remote sensing and models to understand behavioral thermoregulation in dogs

Behavioral thermoregulation is crucial for avoiding thermal stress. Hence, understanding when and how animals might utilize microhabitats for thermoregulation may enable a better risk assessment and conservation planning for animals. However, data on animal location are usually analyzed based on topography, land cover, and other biotic factors, while ignoring microclimate conditions, which may have substantial importance for thermoregulation. Here we integrated microclimate modeling and empirical observations to study how the movement patterns of a searching mammal are affected by thermal conditions, using search-trained dogs as our model animal. In particular, we used GPS tracking to measure how microclimate conditions affected the movement of dogs during their training sessions in a natural forest with nearly 50% vegetation cover, and analyzed the dogs' selection of particular microclimates. To estimate microclimates in the study area, we developed a model that calculates ground temperatures based on meteorological variables obtained from a weather station, the topography and land-cover of the area obtained from a drone. To validate the model, we also used the drone to map the ground temperature under different weather conditions. Interestingly, we found that the dogs' thermoregulation efforts varied between movement and standing. In particular, dogs did not show a preference for a particular microhabitat during movement, but often chose a cooler microhabitat when standing. Our findings highlight the importance of movement analysis and microclimatic mapping when seeking to understand the thermoregulation behavior of animals.

42-2 LAROUCHE, O*; FRIEDMAN, ST; CORN, KA; MARTINEZ, CM; WAINWRIGHT, PC; PRICE, SA; Clemson University, University of California, Davis; *olivierlarouche7@hotmail.com*

Does Habitat Complexity Affect the Direction of Body Shape Evolution in Marine Fishes?

Marine habitats vary widely in structure, from incredibly complex coral reefs through to less complex deep water and open ocean habitats. Hydromechanical models suggest that optimal morphologies differ between these habitats. Simple habitats are predicted to select for sustained efficient swimming, which can be achieved by fusiform body shapes. In contrast, complex habitats are predicted to select for maneuverability, which can be achieved by deep-bodied and laterally compressed forms. To look for a signature of these processes at a broad macroevolutionary scale, we tested for differences in body shapes between fishes living in complex and more simple habitats. We quantified body shapes across 3658 species of ray-finned fishes using a series of linear measurements informative to swimming kinematics. We scored each species for whether they lived in reefs, the most complex marine habitat, or not and tested for morphological differences in a phylogenetic framework. Our results confirmed significant overall shape differences between fishes living in complex and less complex marine habitats. Consistent with our predictions, reef species have on average deeper bodies, lower fineness ratios and higher depth/width ratios, while non-reef species are more streamlined with more tapering tails. Despite the numerous evolutionary forces that may influence body shapes at such a broad macroevolutionary scale, our results support the expected morphological differences predicted from hydromechanical models of swimming kinematics.

79-6 LASALA, JA*; HUGHES, C; WYNEKEN, J; Florida Atlantic University; *jlasala321@gmail.com*

Leatherback Turtle Breeding Sex Ratios are 1:1

As temperatures increase, marine turtles are at risk of a feminization skew within populations due to temperature dependent sex determination. While hatchling sex ratios can be estimated because they are accessible, adult sex ratios remain unknown because breeding females and males are not equally accessible. A functional metric is the breeding sex ratio (BSR), which is estimated from maternal sampling and paternity of clutch samples. Previous estimates of BSR for leatherback turtles (*Dermochelys coriacea*) nesting along Florida's southeastern coast, were not significantly different than 1:1. This estimate did not account for females laying multiple nests per season or that they might may mate between nesting events. We reassess the 1:1 adult sex ratio estimate by analyzing samples from turtles that returned to nest multiple times (2016-2019). We sampled 27 different returning females and a subset of their subsequent nests (n=62 , 760 hatchlings). Females typically did not mate between clutches. Of the females that mated with multiple males, loss of sperm contributions across time was detected. We confirm that females mate at the beginning of the breeding season, and likely do not mate between nests. In Florida, the 1:1 BSR was supported. This leatherback population appears to be decreasing, hence characterizing the mating system is important to population structure now, before extreme environmental effects are evident.

80-1 LATTIN, CR*; KELLY, TR; Louisiana State University, Baton Rouge, LA; *christinelattin@lsu.edu*

Method matters: Considerations for calculating glucocorticoid negative feedback

Because of its critical role in reducing glucocorticoids after exposure to stressors, many researchers have become increasingly interested in assessing hypothalamic-pituitary-adrenal (HPA) negative feedback. Although assessing negative feedback in a standardized way using injections of the synthetic glucocorticoid dexamethasone is a straightforward procedure, there are several defensible ways to quantify negative feedback efficacy, each of which incorporates various aspects of HPA physiology. Here, we report seven different methods for reporting HPA negative feedback and their prevalence in the comparative endocrinology literature, and reanalyze a dataset of wild house sparrows (*Passer domesticus*; n=58) caught during six different times of year to show that even though most of these approaches give values that are correlated with each other, they yield distinct (and even opposing) statistical results. Because the approach used to quantify negative feedback matters so much for the end results, we encourage researchers to converge on a common method for reporting HPA negative feedback, report multiple measures, or at the very least, make their raw data available so alternative measures can be calculated. We also advise caution in comparing results among studies using different approaches to assess HPA negative feedback.

120-1 LAUDER, G V*; WAINWRIGHT, D K; DISANTO, V; WHITE, C; ZHU, J; BART-SMITH, H; Harvard Univ., Univ. Virginia; *glauder@oeb.harvard.edu*

Tuna Robotics: Exploring the High-frequency Performance Space of Swimming Fishes

Tuna and related scombrid fishes are high performance swimmers that often operate at high frequencies, especially during behaviors such as escaping from predators or catching prey. This contrasts with most fish-like robotic systems that typically operate at low frequencies (< 2 Hz). To explore the high-frequency fish swimming performance space, we design and test a new platform based on yellowfin tuna (Thunnus albacares) and Atlantic mackerel (Scomber scombrus). Body kinematics, speed, and power are measured at increasing tail beat frequencies to quantify swimming performance, and to study flow fields generated by the tail. Experimental analyses of freely swimming tuna and mackerel allow comparison with the tuna-like robotic system. The Tunabot (255 mm long) can achieve a maximum tail beat frequency of 15 Hz, which corresponds to a swimming speed of 4.0 lengths per second. Comparison of midline kinematics between scombrid fish and the Tunabot shows good agreement over a wide range of frequencies, with the biggest discrepancy occurring at the caudal fin, primarily due to the rigid propulsor used in the robotic model. As frequency increases, cost of transport (COT) follows a fish-like U-shaped response with a minimum at ~1.6 BL/s. The Tunabot has a range of ~9.1 km if it swims at 0.4 m/s or ~4.2 km at 1.0 m/s, assuming a 10 Wh battery pack. These results highlight the capabilities of high frequency biological swimming and lay the foundation to explore a fish-like performance space for bio-inspired underwater vehicles.

85-5 LAURENCE-CHASEN, JD*; JUNOD, RM; HATSOPOULOS, NG; ARCE-MCSHANE, F; ROSS, CF; University of Chicago; *jdlc700@gmail.com*

Geometric morphometric analysis of tongue shape dynamics during feeding in Macaca mulatta

The tongue plays a crucial role in feeding, but is notoriously difficult to study. Most attempts to quantify the tongue's contribution to chewing and swallowing have been limited to single-plane X-ray video, and thus fail to capture its dynamic shape changes in three dimensions. Here, we use XROMM to measure and quantify 3D tongue shape dynamics during feeding. Two Rhesus macaques (*Macaca mulatta*, both male), were surgically implanted with 24 tantalum markers in the cranium (4), mandible (4), hyoid (1), and tongue (15). Biplanar videoradiographic data were collected while the monkeys fed on grapes, gummy bears, and almonds. Using a new machine learning workflow, at least 1000 gape cycles per individual were tracked, and the motion of the mandible, hyoid, and tongue markers relative to the cranium was reconstructed. A Procrustes superimposition was performed on the tongue marker positions to isolate shape. We then performed a principal component analysis on the transformed data and found that 80% of the variance in the data was explained by the first six principal components. After scaling to percent of gape cycle duration, we compared tongue shape within and across gape cycle types and feeding sequences. As predicted, tongue shape differed significantly between chews and swallows. Notably, these differences emerged as early as the first 10% of the cycle, during the fast-close phase. Finally, the mean variation in tongue shape decreased consistently over the duration of a feeding sequence, reaching a minimum at the terminal swallow. These geometric morphometric analyses reveal global changes in tongue shape independent of tongue or jaw position; our future analyses will quantify the impact of these factors on tongue shape.

21-6 LAW, CJ*; TINKER, MT; FUJII, JA; NICHOLSON, T; STAEDLER, M; TOMOLEONI, J; YOUNG, C; MEHTA, RS; American Museum of Natural History, Nhydra Ecological Consulting, Monterey Bay Aquarium, Monterey Bay Aquarium, US Geological Survey, California Department of Fish and Wildlife, University of California Santa Ccruz; *cjlaw9@gmail.com*

Tool use increases mechanical and bioenergetic foraging success in southern sea otters

Although it is well documented that tool use can facilitate the exploitation of resources, the fitness benefits associated with this innovative behavior are difficult to test. Using longitudinal data from 196 radio-tagged southern sea otters, we examined how variation in tool use frequency contributes to differences in foraging success (both biomechanically and energetically) and longer-term fitness between individuals. We found that individuals, particularly females, with high tool use frequency consumed harder prey items. Furthermore, we found a bi-modal relationship between tool use frequency and caloric income, revealing that not only does frequent tool use lead to greater caloric income but that non-tool using behavior serves as a viable strategy to maintain sufficient caloric requirements. Interestingly, these foraging advantages do not translate to long-term health gains as tool use frequency neither prevented tooth injury nor increased body condition. These results indicate that frequent tool users exhibit greater foraging success by gaining access to relatively harder prey, resulting in greater caloric intake.

108-6 LEAHY, AL*; FISH, FE; KERR, SJ; LEFTWICH, MC; West Chester University, George Washington University; *al916349@wcupa.edu*

Value of the California Sea Lion (Zalophus californianus) Hindflippers during Porpoising and Turning Maneuvers

California sea lions (*Zalophus californianus*) are a highly maneuverable species of marine mammal. They possess four control surfaces in the form of paired foreflippers and hindflippers. Unlike the foreflippers, whose wing-like morphology is fixed, the hindflippers are adjustable in which the digits of the hindflipper can be collapsed (adducted) with a low drag profile or spread (abducted) with a shape similar to a delta wing. During uninterrupted, rectilinear swimming, sea lions oscillate their foreflippers to propel themselves forward without aid from the collapsed hindflippers, which are passively trailed. Sea lions utilize the spread hindflippers during maneuvers, including turning and leaping (porpoising) behaviors. Little has been done to define the role of the hindflippers as a control surface when maneuvering. To examine hindflippers during maneuvering, trained sea lions were video recorded underwater through viewing windows performing porpoising behavior and banking turns. Anatomical points of reference (nose, ankle, and hindflipper tip) were digitized from videos to measure velocity and angle of attack. During porpoising bouts, the average hindflipper angle of attack through the submerged lift-producing phase was 14.6 deg. However, while performing small-radius banking turns, the angle of attack of the hindflippers was much higher, ranging from 25.6 to 35.3 deg. The high angle of attack measured when turning supports the assertion that the hindflippers act as a delta wings to help provide a centripetal force from hydrodynamic lift without stalling to achieve high-performance maneuvers.

45-4 LEARY, CJ; University of Mississippi; *cjleary@olemiss.edu*
Hormonal Regulation of Alternative Mating Tactics in Anuran Amphibians: A Tribute to Rosemary Knapp
Rosemary Knapp was an incredibly influential figure in behavioral endocrinology. Her meticulous work on hormonal regulation of alternative mating tactics set the stage for research in this area and guided many studies in this and other realms. Her knowledge, insight, wit and charm drew admiration from countless students and established scientists alike. Her passing is a major loss. As a PhD student in her lab, Rosemary and I developed some of the first work on hormonal regulation of alternative mating tactics in anuran amphibians. Here I compare our earlier work on toads (*Bufo cognatus*) to current work in treefrogs (*Hyla cinerea*). These two species differ in their ecology and behavior, especially in terms of temporal patterns of reproductive activity and aggression. I discuss how these differences relate to hormone production and conditional adoption of satellite behavior. A common theme that emerges from this work is that circulating glucocorticoid levels play a central role in mediating changes in both mating tactic expression and vocal attractiveness, implicating glucocorticoids as important modulators of sexually selected traits.

17-6 LEBOW, CL*; BURT, DB; TAYLOR, J; Stephen F. Austin State University; *clebow@tds.net*
Glare Reduction Properties of Dark Avian Facial Markings
Avian facial plumage, bill coloration, and feather microstructure may serve one or more adaptive functions. Several researchers have proposed that dark eyestripes, bills, and facial masks aid in reducing glare, however, there have been relatively few tests of this hypothesis. Dark facial markings have been shown to have an adaptive glare-reduction function in recent field studies of a few species, but this hypothesis has never been tested in a broad multispecies analysis. It is likely feather microstructure influences feather brightness and has an effect on the efficacy of glare reduction properties of feathers. We tested the hypothesized link between dark facial markings and glare reduction, under natural lighting conditions, in several bird species using a spectrometer probe placed in the eye-position of museum specimens. Reduction in irradiance in full, natural sunlight, used as a measure of glare, was quantified for specimens varying in bill and head plumage coloration and pattern. Each specimen was tested with the head held at various angles to mimic natural foraging positions. We also quantified the brightness of bills and plumage surrounding the eye of these same specimens using reflectance spectroscopy. Correlations between irradiance measurements and the bill and plumage brightness were analyzed. Facial feather microstructure, barbule density, pith and cortex size were examined using scanning electron microscopy. These characteristics were then compared to plumage brightness of both light and dark patches. We show a significant relationship with average head darkness and reduction in irradiance values when the head was held at 45 degrees from horizontal. Dark patches in the anterior and posterior dorsal quadrants are most important in this reduction in irradiance. Preliminary findings on feather microstructure will be discussed.

37-5 LEDESMA, D*; KEMP, M; University of Texas, Austin; *ledesma-david@utexas.edu*
Changes in central Texas fossil herpetofauna
In the face of modern climate change and worldwide biodiversity loss, it is imperative that we work to better understand the impacts that environmental changes can have on extant populations over long timespans. The study of Quaternary fossils represents an important bridge to the past that grants us insight into how past biota responded to environmental fluctuations and how extant species may respond to future change. I use fossils from Hall's Cave, located on the Edward's Plateau in Kerr County, Texas, to reveal demographic and taxonomic variation in the herpetofauna during the late Quaternary. A reexamination of fossil herpetofauna from Hall's Cave using apomorphic and diagnostic morphology resulted in a different list of herpetofauna taxa than had been previously reported. This result speaks to the merit of using these identification methodologies to provide strong support for fossil classifications and subsequent paleoecological interpretations. I determined the minimum and maximum number of individuals within 5-centimeter intervals for different reptile and amphibian taxa. The two abundance metrics exhibit similar trends through time with changes in abundances of frogs, snakes, and lizards occurring concurrently. Around 1,500-2,000 years ago, there are peaks in abundances of these taxa which coincide with wetter and cooler conditions as reconstructed from previous north-central Texas paleoclimate proxies. Herpetofauna abundances decrease after 1,500 and between 2,500-3,500 years ago, which correspond to warmer and drier time intervals according to published speleothem records. These preliminary results suggest that changes in herpetofaunal abundances from Hall's Cave may be a consequence of past climatic change and provide a glimpse into changes in central Texas' herpetofaunas during the late Quaternary.

86-4 LEE, MA*; DENSMORE III, LD; Texas Tech University, Lubbock, TX; *mark.a.lee@ttu.edu*
Past, Present, and Future Distributions of Agkistrodon contortrix
Changes between past, present, and future climates have noticeable effects on species distribution. For example, temperate reptiles occupy areas today that would have been far too cold in the geologically recent past, and their distribution will likely change as the world becomes warmer. However, species distribution models are usually built using current climatic conditions. While this may give a decent approximation of their current distribution and suitable habitat, it does not elucidate their potential distribution in past climates, nor does it predict changes in their future distribution brought on by climate change. Copperheads (*Agkistrodon contortrix*) are temperate pit vipers that can be found in deserts, forests, prairies, and mountains from southwestern Texas to New England – thriving in varied climatic conditions throughout their range. Due to this adaptability to varied climatic conditions, they may serve as a reference point for changes in temperate reptile distribution brought upon by warming temperatures. Here we used approximately 1,000 geolocations from two citizen science databases, iNaturalist and Herpmapper, to model past, present, and future distributions of this species using non-correlated bioclimatic variables and investigate the rate and extent of change between them. Our results illustrate that copperheads have undergone noticeable changes in their distribution due to climatic change in the past and will likely continue to do so in the face of man-made climate change, albeit at an unprecedented pace. Understanding the effects of climatic variation on temperate reptile distribution can help us understand their evolutionary history and aid in future conservation management plans.

30-1 LEFAUVE, MK*; HERNANDEZ, LP; George Washington University; *mlefauve@gwu.edu*
Invasive Behavioral Syndrome in Cypriniform Fishes
Species are introduced to new environments on a daily basis, but only about 10% do well enough to become an invasive species. Invasive species have successfully navigated the four main steps of invasion: introduction, spread, establishment, and population growth to a detrimental density. These four steps require a unique suite of life history traits to succeed and nowhere is this more apparent than in behavior. When applied across environmental contexts, species-typical behaviors can form a species-wide behavioral syndrome, or suites of correlated behaviors reflecting between-individual behavioral consistency. A "bold" behavioral syndrome has been linked with a higher dispersal potential, a key component of both the spread and establishment steps of the invasion process. Using both a shelter latency and a maze task, we tested species-wide boldness and exploratory drive in a known invasive fish, the goldfish, with comparisons to a noninvasive fish, the giant danio. Within species analysis showed behavioral consistency across environmental contexts for shelter latency, but between species analysis did not show a significant difference due to high individual variation. Total distance traveled in the open field was similar between species, but was significantly different in the maze task ($p<0.05$). Goldfish also spent significantly more time investigating the novel areas of a complex chambered maze task prior to entering a darkened shelter "reward" area. These data are consistent with the hypothesis that invasive species have a higher degree of boldness and exploratory drive than species that are not invasive.

74-2 Lenard, A*; Diamond, S; Case Western Reserve University; *axl710@case.edu*
Butterfly Traits Resolve Variation in Range Shift Responses to Recent Climate Change
Variation in species geographic ranges is astounding – why some species exist on only a small part of one island while others occupy nearly the entire globe has been a key pursuit in biological research for centuries. Over millions of years, ecological and evolutionary forces shaped and continue to shape species ranges. But contemporary species are under novel pressures that could shape their ranges in unprecedented ways. 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. Comparative species trait-based approaches have been used widely to develop generalizable relationships between species-level traits and variation in the range shift response. Here I quantify the range shift responses of butterflies in the midwestern United States to recent climate change over the last several decades. I then explore the potential for butterfly traits including range and distribution attributes, dispersal ability, and thermal niche to explain variation in the magnitude and direction of the range shift response. Finally, I explore how evolutionary history and the evolutionary rate of change in the thermal niche also shape the range shift response. In general, while traits typically examined in this context such as range area were broadly predictive of the range shift response to recent climate change, I also found support for an important role of the evolution of the thermal niche trait. These results suggest that a deeper understanding of the mechanisms that underlie species responses to climate change can aid in predicting where species might be found in the future as the environment continues to change.

112-8 LEIGH, SC*; PAIG-TRAIN, M; California State University Fullerton; *sleigh@fullerton.edu*
The catch of the day is…plastic? The ingestion of microplastics by zooplankton in southern California
Plastic pollution is pervasive in marine environments. While much attention has been given to the effects of macroplastics on a variety of marine organisms (i.e. ingestion and entanglement of large plastic debris by charismatic megafauna), the effects of microplastics in the marine environment are also of major concern and less thoroughly investigated. Given that organisms have been shown to consume microplastics across trophic levels, there is the potential for bioaccumulation of these particles. Zooplankton is a critically important food source for many secondary consumers. Currently, there is limited information regarding the ingestion of microplastics by zooplankton in southern California; a densely populated area with the potential for high quantities of microplastic pollution, as well as an important supplier of commercial fisheries. As such, we categorized the types and quantities of plastic ingested by important zooplankton foundation species through field surveys in four environments within the southern California Bight: 1) LA harbor, 2) a nearshore urban environment, 3) a channel, and 4) open ocean. We have shown that marine zooplankton are ingesting microplastic particles, indicating that species at lower trophic levels of the marine food web are mistaking plastic for food. In a laboratory setting, we have also shown that microplastics can be transferred from brine shrimp (*Artemia salina*) to a predatory moon jelly (*Aurelia aurita*), which raises fundamental questions about potential risks to higher trophic level species within different habitats of the southern California Bight. This represents a path whereby microplastics could enter the food web and transfer up trophic levels, potentially effecting commercially important species that humans rely on for food.

S5-11 LENTINK, D*; CHIN, D.D. ; HIGHTOWER, B.J.; INGERSOLL, R.; Stanford; *dlentink@stanford.edu*
Design principles of Fluid Force and Moment Platforms for biological locomotion studies
One of the key challenges in studying the biomechanics of organisms moving in fluids is measuring the instantaneous fluid force and moment exerted by the organism on its environment. During the past three decades particle image velocimetry revolutionized our ability to measure the associated flow fields in vivo. These flow field snapshots could then be used to approximate the forces by simplifying the governing control volume equations for fluids in various ways, but this approach is not only cumbersome, it also has limited numerical accuracy. During the past decade we invented and dramatically improved a new method to directly measure fluid forces and moments by using force plates that mechanically integrate the pressure and shear stress distributions on the control surfaces of the fluid volume in which the organism moves. Summing the reaction forces and moments acting on these surfaces precisely matches the resulting instantaneous forces and moments exerted by the organism. During the past decade we refined this method for air, enabling us to record the aerodynamic force generated by freely flying birds directly in vivo. The economic recording method gives instantaneous wingbeat-resolved results, which provided new insights in how birds generate and use lift and drag to fly. Here we summarize the design, manufacturing and testing principles of Fluid Force and Moment Platforms in a simple and ready to use format for anyone studying 'life in moving fluids' in the spirit of Steven Vogel. Applications include swimming, running over water, and flight of a wide range of organisms.

96-3 LENZ, AS; School of Biological Sciences, University of Bristol, UK; *anne-kristin.lenz@bristol.ac.uk*

Structural Adaptations of Nepenthes gracilis Pitcher Lids to Capture Insects Using Drop Impacts

Pitcher plants are a group of carnivorous plants that trap and digest prey in their cup-shaped leaves. The traps are passive and have several adaptations to attract and capture prey. In particular the temporarily-slippery peristome and a wax crystal-layer on the inside as well as the viscous fluid in the bottom of the pitcher facilitate the capturing and prevent an escape. In addition to those structures the species *Nepenthes gracilis* has a unique mechanism to capture prey, exploiting the impact energy of rain drops. It produces an increased amount of nectar on the underside of the lid directing prey there. Impacting raindrops accelerate the lid so that insects can't grip to the wax-coated surface and fall into the pitcher. In comparison to those of other, non-specialised species the lid of *N. gracilis* does not bend and reaches a higher speed when accelerated by a raindrop. Previous studies showed that the high stiffness of the lid and a specialized friction-reducing wax-coating on its underside are both essential for its trapping function. Here we report further structural adaptations of the ‘neck' region connecting the lid and the pitcher. We used micro-CT imaging to characterize the three-dimensional deformation during impact and investigate the role of structural reinforcement in the ‘neck' region and pitcher rim, and estimate the reaction forces of the system. A comparison with the non-specialized pitcher plant *Nepenthes rafflesiana* confirmed the crucial role of the ‘neck' region for the function of this exceptional trapping mechanism.

119-6 LENZ, PH*; RONCALLI, V; CIESLAK, MC; CASTELFRANCO, AM; HARTLINE, DK; University of Hawaii at Manoa, University of Hawaii at Manoa and University of Barcelona; *petra@hawaii.edu*

Organism-Environment Interactions in Marine Zooplankton: Transcriptomic Characterization of a Copepod Phenome

The subarctic Pacific is home to the lipid-rich copepod *Neocalanus flemingeri*. With a one-year life cycle, this copepod depends on a short annual spring phytoplankton bloom for growth and accumulation of capital to fuel both diapause and reproduction. This species is highly resilient: its distribution spans the northern Gulf of Alaska, a region where spring food resources vary by one to two orders of magnitude. RNA-Seq was used to profile global gene expression of pre-adult *N. flemingeri* collected across the shelf and in Prince William Sound. t-Distributed Stochastic Neighbor Embedding (t-SNE) analysis of gene expression profiles followed by group identification using the DBSCAN algorithm identified three phenomic clusters. With one exception, these corresponded to three distinct collection regions. Functional analysis of differentially expressed genes identified lipid metabolism as a key biological process contributing to regional differences in transcription. Genes involved in lipid synthesis were up regulated in individuals from Prince William Sound, while genes involved in lipid catabolism were up-regulated in individuals collected in high-nutrient low-chlorophyll (HNLC) gulf waters. Gene expression divergence in *N. flemingeri* indicated acclimatization to local conditions, and a capacity to persist in a habitat with steep resource gradients. We hypothesize that the observed resilience of these copepods stems from a combination of acclimatizion to low food conditions and the ability to exploit pulses of high food to build lipids to fuel diapause and reproduction.

S6-5 LEPIANE, K/L*; CLARK, C/J; University of California, Riverside; *krista.lepiane@email.ucr.edu*

The dorsal velvet surface of owl feathers decreases sounds of rubbing during flapping flight

One wing feature that owls have evolved to silence their flight is the velvet, made up of elongated filamentous projections, or pennula, that stick up on the dorsal surface of feathers. There are two hypotheses as to how the velvet silences flight: aerodynamic noise and structural noise. The aerodynamic noise hypothesis predicts silencing features reduce low frequency sound produced by turbulence development over the surface of the wing. This hypothesis predicts that impairing the velvet will increase low frequency sounds produced during the downstroke, when airspeed over the wing is greatest. Alternatively, the structural noise hypothesis predicts velvet reduces frictional noise, or broadband sound produced when two feathers rub together. Rubbing is likeliest during flapping flight. This hypothesis predicts that impairing the velvet will increase broadband sound produced during the upstroke, when wing deformation causes feathers to rub together. Further, this hypothesis predicts impairing the velvet on regions of feather overlap (trailing vane) will increase sound produced during flight and impairing an adjacent portion of the feather, where there is no feather overlap, will not. To test these hypotheses, we applied hairspray to the dorsal surface of five flight feathers (P1 - S4) on live Barn Owls (*Tyto alba*). We flew owls over a stationary microphone and recorded flight sounds at three experimental conditions: control, manipulation, and manipulation removed. Applying hairspray to flight feathers increased the broadband sound Barn Owls produce during the upstroke, supporting the structural noise hypothesis.

131-1 LESSIG, EK*; NONACS, PN; University of California, Los Angeles ; *elessig@utexas.edu*

Foraging choices, learning, and behavior across paths that vary in risk

Cooperatively foraging species often adjust their search strategies in complex environments to efficiently find and exploit food sources. These strategies become more complicated when food and risk can be simultaneously present and when they differ in predictability. This study examines how colonies of Argentine ants *(Linepithema humile)* learn and respond to negative features of their environments, when potential paths to food differ in the cues that indicate the presence of risk. These cues are either a live competitor (velvety tree ants, *Liometopum occidentale* (LO)) or formic acid (FA), a defensive chemical commonly associated with formicine ant species. The two types of stimuli elicited significantly different behavioral responses, both in path use and time to find food across days. Specifically, *L. humile* were attracted to paths with LO but avoided FA. The intensity of these responses changed over time. The response to FA was constant while the response to LO declined. Further, *L. humile* colonies that were exposed to LO cues were faster at finding food across days compared to colonies exposed to FA. Thus, it appears that *L. humile* foragers assess and respond to features of their environment in order to adopt a successful foraging strategy .

95-2 LEVELL, ST*; REZNICK, DN; University of California, Riverside; *sleve004@ucr.edu*

Can Mothers Diferentially Allocate Resources to Offspring Sired by Different Males?

The Viviparity-Driven Conflict Hypothesis (VDCH) predicts that the mammalian placenta provides a novel arena for parent-offspring conflict over resources. Parent-offspring conflict is a predicted to result from inequalities in the optimal quantity of resources transferred from the parent to the offspring. This conflict is exaggerated if females' mate with multiple males because of lower coefficients of relatedness that result from being a half- rather than a full-sibling. Conflict theory predicts that there will be a reconciliation of conflict within populations but differences among populations in how conflict is resolved. If so, females may be able to recognize and differentially allocate resources to offspring sired by males from her own population. The principles of the VDCH can be extended to matrotrophic (embryonic mother-feeding) livebearing fishes (family: Poeciliidae) such as Heterandria formosa, which is particularly suited to test the predictions of the VDCH because their populations exhibit dramatic differences in offspring size. In this experiment, females from either large-offspring producing or small-offspring producing populations were artificially inseminated with a combination of sperm from males originating from their own population, a different population, or both. Additionally, treatments consisted of either two or four males (with the volume of sperm held constant) to determine whether mating with multiple males affects offspring number or size within and among broods. Preliminary results suggest that the paternal genome dictates offspring size when males from a single population are used. However, when sperm is mixed from multiple populations of males, the size of the resulting offspring is biased in one population.

133-1 LEVENDOSKY, MW*; LANIER, M; BEDORE, CN; Georgia Southern University; *ml06458@georgiasouthern.edu*

Effect of Anesthesia Immersion on the Coral Catshark, Atelomycterus marmoratus

Sensory experiments require anesthesia so the animal is immobilized. Traditional fish anesthetics (e.g. tricaine) depress the sensory system, although the degree to which results are affected is unclear. Newer anesthetics, such as propofol, may offer the same anesthetic relief, but the action of propofol differs from tricaine, so sensory responses may not be affected. Propofol has been used intravenously on small elasmobranchs but may provide prolonged effects if used as an immersion anesthetic. Due to its potential to maintain a surgical plane of anesthesia during sensory physiology experiments, investigation of propofol as an alternative anesthetic warrants investigation. The objectives of this study were 1. Determine the appropriate dose of anesthesia to minimize induction and recovery time for animals anesthetized at a surgical plane of anesthesia and 2. Measure physiological response of the pupil to light stimuli during anesthetic immersion. To address our objectives, we used the coral catshark *Atelomycterus marmoratus*. Respiration rate and response to mechanical stimuli were recorded to measure induction and recovery times in 8 tricaine and 7 propofol doses and generate dose response curves. Appropriate doses of anesthesia are approximately 175 mg L^{-1} tricaine and 1.25 mg L^{-1} propofol. After 1.5 hours of dark adaptation in an anesthetic bath (50, 100, or 150 mg L^{-1} tricaine or 0.5, 1, or 1.5 mg L^{-1} propofol) or no anesthesia (control), tricaine 100 mg L^{-1} trials show reduction in percent pupil constriction ($p<0.5$; ANOVA). While these results suggest propofol may be appropriate for use in sensory experiments, anesthetics are often species specific so the effect of propofol immersion in other elasmobranch species will be investigated.

140-7 LEWIS, ZR*; DUNN, CW; Yale University, Department of Ecology and Evolutionary Biology; *zrlewis@gmail.com*

UV Tolerance in the Portuguese Man of War (Physalia physalis)

The Portuguese Man of War (*Physalia physalis*) is a cnidarian that lives at the surface of the ocean and travels by catching wind in a sail filled with carbon monoxide. A number of aspects of its physiology remain enigmatic, including how it is able to tolerate high levels of UV-radiation (UVR) to minimize cellular and genomic damage. To better understand the mechanism by which *Physalia* survives under regimes of high UVR, we used UV photography to determine the differential UV-absorbing capabilities of *Physalia* tissue types. We extracted and characterized *Physalia's* UV-absorbing molecules using HPLC-tandem mass spectrometry. One class of UV-absorbing molecules are the mycosporine amino acids. Mycosporine amino acids are derived from the same biochemical pathway used to synthesize aromatic amino acids. Enzymes necessary for the synthesis of both aromatic and mycosporine amino acids are thought to be absent in metazoans. Therefore, metazoans must obtain these amino acids from their diet or symbionts. By sequencing *Physalia's* genome, we provide evidence that some of the enzymes for mycosporine amino acid synthesis are present and expressed across most tissues. Additionally, analysis of new cnidarian genome sequence data provides evidence that several other cnidarians endogenously possess enzymes employed in mycosporine amino acid synthesis. Endogenous production of mycosporine amino acids may be one way that *Physalia* manages to thrive under high UVR conditions.

S7-4 LI, J*; LEVITAN, B B; KÜLTZ, D; University of California, Davis; *joli@ucdavis.edu*

Quantitation and comprehension of context-dependent changes of dynamic proteomes

Understanding the complex biochemical mechanisms behind the evolution of salinity tolerance in euryhaline fish is best achieved using systems biology approaches. The proteome provides a wealth of information regarding the molecular phenotype of an organism. The abundance and state of certain proteins indicates life history and environmental exposures. Recent advances in mass spectrometry have allowed for the development of data-independent acquisition (DIA) assays to simultaneously monitor thousands of proteins in virtually any context. Since protein abundance information for only select proteins in response to salinity or temperature challenges provides a limited scope for determining the overall molecular phenotype of an animal, we are continuing to develop comprehensive DIA assay libraries for organisms of interest. These assay libraries permit highly accurate and consistent quantitation of exactly the same sets of proteins in all samples. The consistent proteome coverage enables systematic network and topological data analysis (TDA) approaches that yield detailed mechanistic insight into environmental and developmental effects on organisms. These approaches will be illustrated by discussing salinity and temperature effects on the three-spine stickleback *(Gasterosteus aculeatus)* gill proteome. Our results indicate that differences in habitat salinity and temperature are accurately reflected in the dynamic changes of the gill proteome. Therefore, DIA quantitative proteomics assays and corresponding bioinformatics analyses enable deduction of molecular mechanisms associated with environmental changes in aquatic organisms. This work was supported by NSF grant 1656371.

4-5 LI, DH*; KATIJA, K; GILLY, WF; Stanford University, Monterey Bay Aquarium Research Institute; *dhli816@gmail.com*
Hydrodynamic constraints on jet propulsion in squid paralarvae at intermediate Reynolds numbers
Squid are known for their use of jet propulsion, and paralarvae rely on this locomotor strategy immediately after hatching. Unlike their adult counterparts operating at high Reynolds number (Re) where inertia dominates, paralarvae must contend with both inertial and viscous forces in intermediary Re regimes. Observations of jet wake structure in squid paralarvae reveal that vortex rings, a key feature in potential thrust and efficiency enhancement, appear distorted when compared to observations in adults at high Re. It is possible that viscosity plays a role in changing jet wake structure, with consequences for the effectiveness of jet propulsion as Re decreases. Numerical simulations on how Re affects jet propulsion have proposed a theorized limit at Re = 10, below which swimming speeds quickly decay and jetting is no longer effective. By using micro particle tracking velocimetry to visualize jet hydrodynamics of tethered and free-swimming squid paralarvae in seawater and in fluids with twice and four times the viscosity of seawater, we find experimental evidence supporting the idea of a critical limit for jet propulsion. When Re < 10, significantly less thrust is produced and vorticity in the wake is disorganized with no evidence of coherent ring structures. Moreover, paralarvae are unable to swim under such conditions even though the magnitude of mantle contractions increases. For a dynamically similar scenario in seawater, a paralarva would have to be smaller than that for any known species of squid, suggesting that viscous forces at low Re may play a role in hydrodynamically constraining size at hatch for these small, jet-propelled organisms.

96-2 LIAO, JC*; AKANYETI, O; Whitney Lab for Marine Bioscience, University of Florida, Aberystwyth University, Ceredigion UK; *jliao@whitney.ufl.edu*
How fishes use body wave interference to accelerate
The ability for fishes to move fast is critical for successful prey capture and predator evasion. Here, we uncover the physiological and hydrodynamic mechanisms of a previously undescribed method of propulsion which allows undulating fishes to double their maximal swimming speeds; they do this by superimposing a low-amplitude impulse wave onto their main undulatory wave. Analogous to constructive interference in physics, the impulse wave enhances the transfer of the body momentum to the wake by snapping the tail like a whip, propelling the fish forward in ways that would not be possible with classical undulatory movements. The superimposed impulse wave increases tail tip velocity independently without increasing the body wave speed. Our preliminary data (n=3 rainbow trout, L=22.4±2.0 cm) show that during whipping, an impulse wave is initiated in the region of the dorsal fin. Trout regulate timing and speed of the impulse wave in a way that increases the lateral amplitude of the tail tip excursion up to 20% compared to fish swimming steadily. This allows fish to increase tail tip velocity and angle of attack by 40% and 15°, respectively. Our results also show that a whipping fish generates optimal vortex rings with much higher circulation than those observed during undulation at a comparable speed. We hypothesize that during whipping fish separate muscle functions by coordinating undulatory and impulse waves independently. We predict that red muscles continue powering body undulations as in steady swimming, whereas a transient burst of local white muscle is responsible for the initiation and transmission of the impulse wave.

7-4 LIDGARD, AD*; FRENCH, SS; HUDSON, SB; Utah State University; *audrey_lidgard@yahoo.com*
Stress Sensitivity to Temperature in Plateau Side-blotched Lizards (Uta stansburiana uniformis): Implications for Immune Function
Ectothermic organisms, such as reptiles, rely on the external environment for regulating internal temperatures necessary for vital physiological processes. When faced with environmental challenges, temperature may differentially affect how allostatic mediators (e.g., glucocorticoid hormones) are released to mediate energy allocation for handling stressors. Subsequent differences in energy mobilization and circulating metabolites during a stress response may ultimately influence self-maintenance processes such as immunity. The aims of this research were to determine how stress sensitivity varies with diurnal temperatures in the Plateau Side-blotched Lizard (*Uta stansburiana uniformis*) and to assess the potential implications for immune function. Both baseline and stress-induced levels of glucocorticoids (corticosterone) and energy metabolites (glucose) were compared to body temperature and the thermal environment. Variation in innate immune function (bactericidal ability) was then compared to both temperature and physiological parameters at baseline and stress-induced levels. Stress reactivity via glucocorticoid release positively corresponded with body and environmental temperatures, although glucose release did not. Bactericidal ability subsequent to a stressor negatively corresponded with body temperature and glucocorticoid release. Such findings provide further insight on how stress sensitivity and self-maintenance can vary across the thermal environment, posing potential fitness consequences for an ectothermic organism.

116-4 LIEBL, AL*; DUPREY, ER; RUSSELL, AF; University of South Dakota, University of Exeter; *andrea.liebl@usd.edu*
What is the relationship between developmental stress hormones and adult helping behavior in a cooperatively breeding bird?
Cooperative breeding behavior is a paradoxical behavior wherein some individuals forego breeding to help raise the offspring of other individuals. In many cooperatively breeding species, individuals tend to help raise related offspring, thus increasing their own fitness indirectly; however, even within these systems, considerable variation exists in helping behavior among individuals that cannot be explained by relatedness. Here, we predicted developmental experience may help explain some of this variation. In particular, we focused on developmental stress hormones which have been shown to be predictive of adult morphology, physiology, and behavior in other species. Using the obligate cooperative breeding chestnut-crowned babbler (*Pomatostomus ruficeps*), we measured feather corticosterone in chicks just before fledging. We predicted feather corticosterone would be related both to developmental environment (specifically, number of helpers) and to adult cooperative behavior. Helpers in this species help by provisioning nestlings and, unsurprisingly, the number of helpers is positively related to the amount of food provisioned to each brood. Surprisingly, we found a positive relationship between feather corticosterone and helper number. Analyses between feather corticosterone and adult provisioning behavior are still ongoing. However, identifying the proximate mechanisms that drive variation in cooperative behavior may also begin to explain the ultimate mechanisms by which cooperative breeding has evolved.

48-3 LIGUORI, AL; Stony Brook University;
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Exploring local adaptation to salinity and temperature variability in the copepod Tigriopus californicus
Local adaptation has been studied in a broad range of taxa for decades. However, we have limited understanding of how often local adaptation occurs in variable environments. Whether phenotypic plasticity can evolve in distinct ways among populations experiencing different patterns of abiotic variability is unclear. Abiotic conditions in coastal marine habitats can be highly heterogeneous, which might promote local adaptation. *Tigriopus californicus* (tidepool copepod) populations on San Juan Island, WA have distinct morphology and life history. The goal here was to test whether these differences are a result of local adaptation, and to quantify responses to different magnitudes of temperature variation. To identify potential selective pressures in the field, temperature and salinity were measured in high shore pools for 6 months. A common garden experiment with factorial combinations of 7 temperature and 2 salinity (32, 55 ppt) treatments was conducted on 3 populations. Two temperature treatments varied daily, both with an average of 20°C, but different ranges (low amplitude: 15-25°C, high amplitude: 10-30°C, 12:12 hour exposure). The other 5 treatments were the average, maximum, and minimum temperatures held stable. Fecundity, survivorship, and development were characterized across two generations. Preliminary results show differences in abiotic variability among sites, despite their geographic proximity. The experiment revealed strong effects of temperature on fecundity and survival, but these effects were not the same among populations. Abiotic patterns in the field did not seem to explain the observed population differences, thus limited evidence for local adaptation was found. For these populations, differences in selective pressures among sites might not be strong enough to overcome the influence of genetic drift.

S2-8 LINDNER, M; VIITANIEMI, H; VAN OERS, K; VISSER, M; LAINE, V; VERHAGEN, I; HUSBY, A*; Netherlands Institute of Ecology, University of Helsinki, Uppsala University;
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Epigenetic regulation of seasonal timing of reproduction
Seasonal timing of reproduction in plants and animals is an important trait closely associated with fitness but the molecular genetic mechanism behind seasonal timing is not well understood. I will review some recent attempts at understanding the molecular genetic mechanism behind timing of reproduction where we have used within indivdual (longitudinal) sampling to examine changes in DNA methylation across the breeding season using great tits (Parus major) as a model organism. Our recent work demonstrate both temporal genome wide change in methylation over the breeding season and also rapid changes in methylaiton in the regulatory region of some previously identified reproductive genes around the date of first egg laying in this species. These findings demonstrate and further establish that epigenetic mechanisms such as DNA methylation can be an important mechanism in regulating seasonal timing of reproduction.

AMS-1 LINDSAY, SM; University of Maine, Orono;
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The Art of Seeing: Using Microscopy to Power STEAM Learning in Biology
Close observation is central to both art and science, as practitioners in both disciplines describe, compare, and seek to understand or interpret the natural world. Indeed, as the artist and writer Guy Davenport noted, "The vision by which we discover the hidden in nature is sometimes called science, sometimes called art". In the last decade, the movement to integrate Science, Technology, Engineering and Mathematics with Arts and Humanities (i.e., STEAM learning) has gained traction in K-12 education. A recent National Academies report (2018) examines the case for integrating humanities and the arts in undergraduate STEM education. Microscopy provides an excellent vehicle for engaging all kinds of students in integrative (STEAM) learning about Biology and for encouraging them to observe the world closely. In this address, I will highlight activities and approaches that use microscopy to engage learners of all kinds, examine how using microscopes changes students' attitudes about science and biology, and explore the intersection of microscopy and visual art.

S4-6 LIPSHUTZ, SE*; ROSVALL, KA; INDIANA UNIVERSITY;
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Neuroendocrinology of sex-role reversal
Across the animal kingdom, females of some species are "sex-role reversed," suggesting they face stronger competition for mates than males do. Sex-role reversal is often associated with additional life history traits, such as male-only parental care and female-biased dimorphism in ornamentation, weaponry, and body size. While much attention has been paid to behavioral and morphological sex differences, less is known about the physiological mechanisms underlying sex-role reversal. We review the hormonal, neural, and genomic evidence that females are physiologically 'reversed' from systems with 'conventional' sex roles. We evaluate largely untested hypotheses on the interplay between sex-roles, physiology, and the resolution of trade-offs between mating and parental effort.

102-2 LITTLER, A*; GARCIA, M; TEETS, N; University of Kentucky; *asli226@uky.edu*

Does a Well-Balanced Diet Keep You Going When the Going Gets Cold?

Cold stress is detrimental to insect fitness and has driven the evolution of coping mechanisms for low temperature stressors. Ecological factors including seasonal shifts in day length and temperature influence an insect's cold tolerance, and recent studies have suggested that diet may also impact insect cold tolerance. However, the components of an insect's diet that are most important for cold tolerance, and how their effects differ among genetically distinct individuals, remain unclear. In this study we determine which dietary component are crucial to insect cold tolerances using the fruit fly, *Drosophila melanogaster*. Specifically, we examine the impact of four commonly used fly foods on: 1) insect cold tolerance, 2) reproduction, and 3) the ability to maintain reproduction after cold stress. We selected six, distinct isogenic fly lines which vary in basal cold tolerance and reared them on four standard diets that vary in their nutritional content. We then measured cold shock survival, total reproductive output, and reproductive output following cold exposure. Current results show that nutrition significantly influences cold tolerance, and that these dietary effects vary by genotype. In ongoing experiments, we are identifying whether diet affects reproduction and the protective effects of diet on reproduction following cold stress. Ultimately, we seek to understand the extent to which diet influences fitness-relevant traits like cold tolerance and the importance of diet for the evolution of these fitness-related traits. Practically, our results indicate that diet selection is an important consideration when designing a cold tolerance experiment.

S11-8 LIU, Y; University of Texas Southwestern Medical Center, Dallas; *yuxiang.liu@utsouthwestern.edu*

The Era of Single-Cell Sequencing: Lessons from Comparative Cognition of Model Organism

Comparing with non-human primates, we evolved unique cognitive abilities which have been attributed to high volume of human brain especially the expansion of prefrontal cortex (PFC). To understand gene regulatory mechanism underlying human brain specialization, a comparison of cortical transcriptomes between human and closely related primates revealed that human CLOCK (huCLK) is up-regulated in human PFC. However, how huCLK results in human brain specializations? To address the question, we firstly generated humanized (HU) mice which overexpress huCLK in CLK-knockout mice to mimic relative expression of CLK in human versus other primates. Through a battery of cognitive tests, we found that HU mice showed similar activity, anxiety, and general learning abilities as wildtype (WT) mice, while HU mice outperformed WT mice in social learning and cognitive flexibility both of which are PFC dependent cognitive abilities. We then leveraged immunohistochemistry to compared neuroanatomical characteristics of PFC between genotypes. Results show that HU mice did not alter cortical thickness and lamination while they possessed higher density of neuron and oligodendrocyte than WT mice. To understand gene regulatory mechanism behind the alternations of HU mice, we did single-nuclei RNA-Seq in PFC of young adult mice (8 weeks). Preliminary analysis shows that nuclei of HU mice are enriched in an interneuron cluster and an oligodendrocyte cluster. More results, such as differential expression and pathway analysis are in progress. In summary, we found that overexpression of huCLK resulted in improved cognitive flexibility, higher neuron and oligodendrocyte density, and alternation of cell composition in PFC. These results suggest that huCLK might play an important role in proliferation and differentiation of cortical cells under the evolution of human brain.

46-7 LOCHAB, AK*; EXTAVOUR, CG; Harvard University; *alochab@g.harvard.edu*

Traveling Without a Destination: Primordial Germ Cell Migration in a Hemipteran Insect

In many animal species, the first line of restricted germ cells (Primordial Germ Cells) are formed in a location independent from the site of gonad development. In these species, the germ cells must migrate to the future gonad location before they are incorporated into the developing gonads. In some animals, such as *Drosophila melanogaster*, the tissue where PGCs will end up has already been specified when the PGCs begin migrating. However, in other animals, including the hemipteran insect, *Oncopeltus fasciatus*, PGCs begin migrating before the cells of their final resting place have been formed or been given an identity. In this insect, the mechanisms used by PGCs to find their location while the abdominal segments are growing and being specified around them remain unknown. Similarly, during this process, whether PGCs exhibit active cell migration and/or passive movement driven by the surrounding tissue that is growing is an open question. As a first step towards elucidating these mechanisms, we aim to characterize the cellular dynamics of PGCs moving through the surrounding embryonic tissue. We also aim to determine the molecular identity of the directional cues that eventually guide PGCs to the correct abdominal segments. Here we present progress on (1) a quantitative description of PGC migration, and (2) a candidate gene approach to determine the molecular basis of this process.

113-7 LOCPORT, JK*; DANIEL, TL; WILLIS, MA; University of Washington, Case Western Reserve University, University of Washington, Case Western Reserve University; *jkl60@case.edu*

Agent-based Models of Insect Odor Tracking Based on Behavior Experiments

Previous behavioral studies in American cockroaches, *Periplaneta americana*, show they can track an odor plume even when all but a small portion of one antenna is lost. Their tracking performance improves with increasing amounts of antenna present whether bilateral symmetry is preserved or not. These observations lead us to propose an agent based model featuring spatial and temporal integration across an antenno-topic map to describe how *P. americana* tracks an odor plume. We focus on three models of how brains use the odor information detected by antennae. One model integrates across the antennae spatially and temporally, one compares between the two antennae bilaterally, and one compares concentration over time. We tested these models with nine different antennal configurations consisting of three arrangements (two bilaterally symmetric antennae, one antenna on the left, or one on the right) and with three different antennal lengths (10 mm, 20 mm, and 40mm). We modeled the plume using a computational fluid dynamic model coupled to diffusive mass transport. Additionally, electroantennogram and photo-ionization detector recordings provided validation of the plume structure. The integrative model is relatively inefficient (search paths are long), but robust against any type of missing antenna segments. Whereas, the bilateral comparison modelis more successful (higher fraction finding the source) but fails with a loss of one of the two antennae. Meanwhile, the purely temporal comparison model is remarkably robust, showing high levels of success in all but the highest noise trials.

103-5 LOHMANN, KJ*; BROTHERS, JR; LOHMANN, CMF; University of North Carolina at Chapel Hill; *klohmann@email.unc.edu*

No Place Like Home: Sea Turtles and Geomagnetic Imprinting

Various marine animals migrate across vast expanses of ocean before returning as adults to reproduce in the areas where they originated. How animals accomplish such feats of natal homing has remained an enduring mystery. Studies with sea turtles, however, have provided evidence that turtles imprint on the magnetic field of their home area when young and use this information to return as adults. Behavioral experiments indicate that turtles have the sensory abilities needed to detect the unique 'magnetic signature' of a coastal area. In addition, analyses have revealed that subtle changes in the geomagnetic field of the home region are correlated with changes in the distribution of nests along beaches. A relationship between population genetic structure and the magnetic fields that exist at nesting beaches has also been detected, consistent with the hypothesis that turtles recognize their natal areas on the basis of magnetic cues. Taken together, the results imply that geomagnetic cues play a central role in the natal homing of sea turtles and, in many cases, can fully account for a turtle's ability to return to a specific home beach. Similar mechanisms may underlie long-distance natal homing in diverse marine migrants such as fish and marine mammals.

82-3 LOLAVAR, A*; WYNEKEN, J; Florida Atlantic University; *alolavar@fau.edu*

The impact of sand moisture on the temperature-sex ratio responses of developing loggerhead (Caretta caretta) sea turtles

All species of sea turtles exhibit a cooler male/warmer female temperature-sex ratio response. Field and experimental studies on loggerhead sea turtle sex ratios suggest that increased sand moisture impacts sea turtle sex ratios with, and perhaps beyond, a cooling effect. This study examines how varying sand moisture impacts the embryo's response to temperature. In 2016-2018, we collected loggerhead sea turtle (*Caretta caretta*) eggs and transferred them into boxes. Across three years, eggs were incubated at temperatures ranging from 28.0°C to 33.0°C. Groups of eggs were incubated in one of three volumetric moisture contents: low, medium, or high. Temperatures inside the group of eggs were recorded throughout incubation. Hatchlings were transported to the Florida Atlantic University Marine Laboratory where they were raised for 2–3 months and sex was identified laparoscopically. We calculated temperature response curves for groups of eggs incubated at each moisture level. Pivotal temperatures did not different among eggs incubated in different sand moistures. The transitional range of temperatures (TRT) for eggs incubated in high moisture and low moisture was narrower than the TRT for eggs incubated in medium moisture. The results of this study are crucial for understanding how sea turtle embryos respond to temperature under different moisture conditions. Current sex ratio predictions rely on the embryos response to temperature only and may inaccurately estimate sex ratios especially during periods of heavy rainfall or drought.

85-2 LOMAX, JJ*; BRAINERD, EL; Brown University, Brown University ; *jeremy_lomax@brown.edu*

Comparative Skeletal Kinematics of Overbite-Shearing and Compressive Chewing Cycles in a Pacu Fish, Piaractus brachypomus

Pacus are a group of herbivorous fishes known to extensively process a variety of plant materials with their oral jaws by means of their robust incisiform teeth. This method of mechanical breakdown, while common in mammalian species, is less frequently observed in fishes, leaving the biomechanics of this processing behavior largely unknown. Using X-ray Reconstruction of Moving Morphology (XROMM), this study found similarities between the processing behavior of one species of pacu, *Piaractus brachypomus*, and a chondrichthyian species, *Potamotrygon motoro*,. Much like the freshwater stingray, *P. brachypomus*, alternates between periods of short compressive chews, where the amplitude of mandible rotation is small but food is still actively engaged between the teeth, and periods of extreme rotation of the lower jaw which result in the shearing of food between the mobile dentary and the stationary premaxillary teeth. In the pacu species, the exaggerated overbite motions of the lower jaw are facilitated in part by the morphology and motions of the hyomandibula. In most ray-finned fishes, the hyomandibula-neurocranial joint is a straight and flat hinge joint, effectively permitting only abduction and adduction of the suspensorium. However, the articular surface of the hyomandibula in *P. brachypomus*, is rounded at its joint with the neurocranium, contrary to the typical actinopterygian condition, and contrary to the largely carnivorous relatives of the pacu, piranhas. The rounded surface appears to permit rostro-caudal rotation of the suspensorium which in turn facilitates periods of overbite shearing during the pacu processing cycle.

58-6 LONG, JH*; AARON, E; LIVINGSTON, K; HAWTHORNE-MADELL, J; Vassar College, Poughkeepsie, NY, Colby College, Waterville, ME; *jolong@vassar.edu*

Evo-Devo Biorobotics: Masquerading Genomes and the Mapping of Genotype to Phenotype in Embodied Agent Models

By Barbara Webb's codification, biorobots test hypotheses about biological systems. While those systems may be particular organisms, they may also be processes. Evolution, for one, has been modeled in embodied robots to test hypotheses about the origin of early vertebrates. But explicit models of development, the mapping of genotype to phenotype, have been wanting. Thus our work extends evolutionary biorobotics to include development, allowing the two processes to be studied as they interact. Specifically, we test the hypothesis that random errors in transcription feed back to the genotype over generational time to increase genetic variance of the population and alter the evolution of morphological complexity. Key to this process is that random errors in development create *masquerading genomes*, individuals with indeterminate mapping of genotype to fitness. We digitally simulate populations of autonomous mobile robots in which genomes encode morphological and neural structures, spatial relations, and regulatory elements; the interactions of structures and regulatory elements unfold in an explicitly modeled developmental process. We simulated 11 levels of genetic mutation rate and transcription error rate in 10 populations of 60 robots over 100 generations, with fitness determined by a simple locomotion task. In the presence of directional selection, genetic variation was proportional to the rate of transcription error. Moreover, transcription error and mutation acted independently and in different ways on the evolutionary dynamics of the population. This work was funded by the U.S. National Science Foundation (grant no. 1344227, INSPIRE, Special Projects).

29-2 LONGO, SJ*; COX, SM; AZIZI, E; ILTON, M; OLBERDING, JP; ST. PIERRE, R; PATEK, SN; Duke University, Pennsylvania State University, UC Irvine, Harvey Mudd College, UC Irvine, Carnegie Mellon University; *sjlongo@ucdavis.edu*

Beyond power amplification: new insights from latch-mediated spring actuation (LaMSA)

Organisms across the tree of life have evolved mechanisms to perform extremely rapid movements by temporarily storing energy in elastic structures (springs) and then mediating the release of that energy using latches. These types of mechanisms were first described in jumping insects, where it was shown that the power output of a spring-actuated mechanism mediated by latches resulted in mechanical power outputs exceeding muscle power outputs. The phenomenon, called power amplification, became an important diagnostic tool for biologists to discover elastically-driven animal movements. With the introduction of accessible high-speed high-resolution video equipment, spring-actuated movements have been described in a wide diversity of organisms and for a surprising array of uses. Examples now include many organisms that do not possess muscle, and are therefore not limited by muscle power limits, such as plants and fungi that use elastic mechanisms for ballistic seed or spore dispersal. In addition, while the presence of latches in elastic mechanisms has long been appreciated, recent work highlights the central role that latch characteristics play in mediating energy transformations. We will highlight how focusing on the shared underlying components in these systems (springs, latches, and actuated masses) has given new insights into the trade-offs and considerations for diversity and tuning. Some examples utilizing the latch-mediated spring actuation (LaMSA) framework in snapping crustaceans and rapid feeding mechanisms in fish will illustrate how LaMSA can stimulate new avenues for studying evolution, control, and performance.

58-4 LOPEZ JUAREZ, J*; VENTURA, D; ZHANG, L; DAVIDSON, B J; Swarthmore College; *jlopezj1@swarthmore.edu*

Developmental systems drift in tunicate neural gene regulatory elements

Developmental mechanisms often remain stable despite changes in the architecture of underlying gene regulatory networks (GRNs). This evolutionary process is termed developmental systems drift. We explore developmental drift through comparisons of tunicate GRNs, including the recently assembled genomes of Corella inflata and Boltenia Villosa along with that of the well-characterized model organism, Ciona robusta. We have begun to deploy this comparative analysis to examine changes in the regulatory elements for three different neural genes (Otx, DMRT, and Foxc). Despite any discernable sequence conservation, regulatory elements for the Corella Inflata orthologs to these genes are capable of driving neural expression in Ciona embryos. These Corella elements contain binding motifs for upstream trans-factors (Ets and GATA) characterized in Ciona. This preliminary data suggests that drift has occurred in the arrangement of binding sites while upstream trans-factor inputs have remained constrained. However further testing is required to determine whether these candidate sites are required for regulation of neural gene expression in Corella. We have also identified regulatory elements for Boltenia orthologs of two of these neural genes (DMRT and Otx) along with three cardiac progenitor lineage genes (Mesp, FoxF and Hand-like). Corella and Ciona are much more closely related to each other then they are to Boltenia villosa. Thus, comparisons between all three species will help to address questions about the rate and nature of developmental drift across different levels of divergence.

12-1 LORD, NP*; WELLER, HI; SHARKEY, CR; Louisiana State University, Brown University, University of Minnesota; *nlord@lsu.edu*

The Color of Jewels: Evolution of Color Patterns Across a Speciose Lineage of Jewel Beetles

Animal coloration is a fundamental aspect of visual communication (*e.g.*, sexual selection, aposematism) and crypsis (*e.g.*, camouflage, mimicry). Insect coloration is largely determined by either pigmentation, local nanostructures, or a combination of both. A number of structural optical mechanisms are employed, producing striking visual effects including iridescence and polarization. While the totality of visual signal produced is incredibly complex to tease apart in a biological context, an important initial step is to determine what aspects of visual signal(s) are present and how they are produced. Recently, a number of new image analysis packages and toolboxes (*e.g.*, colordistance, micaToolbox, NaturePatternMatch, pavo2, patternize) have been released. Here we used these tools to analyze digital image data across a speciose lineage of jewel beetles (Buprestidae: *Chrysochroa*), a group that displays a dazzling array of both structural iridescence and pigmented colors, alongside a visual system that exhibits diverse wavelength sensitivity. We used these data to investigate phylogenetic, taxonomic, biogeographic, and natural history components of a beautiful, yet classification-challenged group of economically important beetles. While visual signals will always remain an inherently complex system to study both qualitatively and quantitatively, repeatable measurements and statistical analyses of these data are advancing rapidly, paving the way for foundational exploration necessary to inform more rigorous spectrophotometric measurements and to precede formative behavioral studies.

41-6 LOVE, AC*; GRISHAM, K; DURANT, SE; University of Arkansas, Oklahoma State University; *ashley.c.love@okstate.edu*

Perception of Infection: Public Information about Disease Influences Immunity in Songbirds

Sick animals often provide visible cues that they are infected through behaviors such as lethargy, and physical signs, such as inflammation and lesions. The detection and avoidance of sick conspecifics is common among animals, but less is known about how viewing diseased conspecifics influences an organism's physiological state. Work in humans suggests that visual cues of infection are capable of stimulating the immune system, presumably to help the body prepare for an impending immune threat. Whether visual cues of disease can also induce changes in immunity in non-human organisms is not well understood, however if organisms can adjust investment in immune defenses to match the probability of pathogen exposure this could have important implications for disease transmission dynamics. The avian pathogen *Mycoplasma gallisepticum* (MG) is an ideal tool for investigating how the perception of social cues of disease shape immunity in healthy individuals, as infection with this bacterium causes obvious visual signs of infection, including lethargy and conjunctivitis. We tested whether social information transmitted by MG-infected individuals can stimulate innate immune responses in domestic canaries housed in visual contact with either healthy or MG-infected conspecifics. We found that immune profiles differed between birds viewing sick and healthy conspecifics. Specifically, we observed immune activation in healthy birds viewing MG-infected individuals around 6-12 days post-inoculation, which is when infected stimulus birds exhibited the greatest degree of disease pathology and lethargy. These data indicate that social cues of infection are capable of altering immune responses in healthy individuals and suggest that public information about disease could play a role in shaping individual variation in disease susceptibility.

41-3 LOVE, AC; DURANT, SE*; WILDER, SM; YOUSEFF, NH; U Arkansas, Ok State; *sedurant@uark.edu*

Macronutrients, the microbiome, and illness-induced feeding behavior: Are birds shaping immune responses through selective feeding?

The importance of specific macronutrients to immune processes is partly due to their ability to provide the building blocks of immunoproteins and fuel expensive immune responses. More recently we have begun to appreciate that macronutrient content of the diet also can affect immune processes through the gut microbiome. In this study, we conducted two experiments. The first explored whether birds exhibit shifts in the gut microbiome community and immune responses when fed isocaloric diets differing in macronutrient ratios, specifically lipids and proteins. We then designed an experiment to determine whether birds alter macronutrient intake when presented with an immune challenge. We found that macronutrient content of the diet changed the relative abundance of microbes, but not the diversity of microbes present in the gut. Despite changes in the gut microbiome, we did not find effects of diet on the physiological endpoints we measured, complement activity and corticosterone concentrations. However, birds given the choice of isocaloric diets high in either protein or lipids, then injected with an immune antigen (lipopolysaccharide; LPS), exhibited illness-induced anorexia that was macronutrient specific. Birds decreased intake of the protein rich diet, but maintained intake of the lipid rich diet. These results indicate that birds exhibit selective feeding when immune challenged, presumably because lipids provide a larger caloric gain than proteins, and proteins can benefit pathogen growth. Although we did not detect macronutrient-specific effects on complement activity, immune effects may still occur and could be more apparent with a more severe immune challenge.

132-4 LUCAS, KN*; LAUDER, GV; TYTELL, ED; University of Michigan, Harvard University, Tufts University; *kelsey.n.lucas@gmail.com*

Revisiting Dubois: the roles of positive and negative pressure in force production during fish swimming

In biomechanics classes, many of us have been shown the classic figure of pressure along a fish's body during swimming: high pressure on the head, negative pressure along much of the body, and positive pressure on the caudal fin. This figure was the result of a series of seminal works by Dubois and colleagues, who implanted pressure sensors into the skin of fish to measure the pressure gradients generated by their carangiform swimming movements. Using our new techniques for quantifying pressure and force distributions at high temporal and spatial resolutions, we revisit these findings. On average, the profile matches the classic figure. But instantaneously, the pressure gradients oscillate substantially around this average. Negative pressure contributes on average 42% of total thrust, and the anterior body produces 36% of total thrust. Further, temporal patterns of positive and negative pressure around the caudal fin suggest that negative pressure may play a key role in the timing of thrust delivery. These relatively subtle shifts can substantially change thrust production during swimming, and since swimming is an essential component of many fish behaviors, it is tied to the evolution of fish body forms and ecological roles. By leveraging these new methods to understand force production mechanisms, future work will reveal evolutionary pressures leading to the diversity of body forms we see in fishes today and inspire designs for fast, efficient underwater vehicles.

42-7 LUNGMUS, JK*; ANGIELCZYK, KD; LUO, ZX; University of Chicago, Field Museum of Natural History; *jlungmus@uchicago.edu*

Limb Ecometrics Show Limited Applicability for Quantifying Ecological Novelty in the Deep Evolution of Synapsida

Mammalia are the only living members of the larger clade known as Synapsida, which has a fossil record spanning from 320mya to today. Despite the fact that much of the ecological diversity of mammals has been considered in light of limb morphology, the origin of broader synapsid limb diversity and its influence on ecological diversity has received less attention. Here we present shape analyses of the forelimbs of the multiple fossil synapsid radiations in comparison to a broad sample of extant Mammalia. Previous work by the authors has shown that shape broadly is not informative of specific locomotor ecomorphologies in earliest fossil Synapsida. Considering the broader scientific use of limb morphology in testing for fossil ecomorphologies, we sought to better understand at what juncture in synapsid evolutionary history do limb metrics begin to show utility in ecomorphological analyses. Shape data on humeri and ulnae elements from an extant sample representing known ecomorphologies provided the framework for a comparative study of extinct ecomorphologies, associated specifically with locomotion. We conducted linear and geometric morphometric comparisons between the extant sample and five taxonomic subsampled radiations moving crown-ward along the synapsid lineage. Taxonomic designations were the PermoCarboniferous "pelycosaurs", both Permian and Triassic therapsids, "Non-mammaliaforme cynodonts", and "Mammaliaformes". Results show that many limb ecomorphological metrics commonly used are not effective designators until close to the origin of crown Mammalia, as late as the Jurassic. This brings into question the overall utility of using extant analogues to test for ecological signal in a given tetrapod group's deepest fossil ancestors.

6-6 LUNSFORD, ET*; LIAO, JC; Whitney Laboratories for Marine Bioscience, St. Augustine, FL; *elunsford@ufl.edu*

Lateral line activity is attenuated during the glide phase of intermittent swimming behavior

Accurate sensory processing during movement requires the animal to distinguish between external and self-generated stimuli to maintain sensitivity to biologically relevant cues. Descending modulatory inputs from the brain have long been hypothesized to be a principle mechanism for filtering sensory reafference in the periphery via corollary discharge during muscle activation. The lateral line system in fishes is a mechanosensory organ that experiences sensory feedback via detection of self-generated fluid motion during swimming. We simultaneously monitored motor neuron commands and spontaneous lateral line afferent activity during and after swimming. Lateral line afferent activity was reduced during swimming, but was not fully inhibited in all cases. The attenuated spike frequency was sustained even after the offset of motor activity indicating the inhibitory control was not confined to the duration of the swim. This reduction in spike rate was substantial and only returned to intrinsic spontaneous spike rates after a well-defined refractory period. We quantified the anticipated influence the refractory period would have during the glide phase of intermittent burst-and-glide swimming behaviors. The relationship between the proportion of time the refractory period overlaps with the glide duration to tail-beat frequency and swim duration reveals that employing fast, short swimming strategies minimizes lateral line desensitization during the glide period. Our results detail a neuromodulatory mechanism in larval zebrafish that adaptively filters self-generated flow stimuli during both active and passive phases of locomotion.

S4-10 LYNCH, KS*; RYAN, MJ; Hofstra University, University of Texas at Austin; *kathleen.lynch@hofstra.edu*
Social Regulation of Hormones and the Implications for Female Mate Choice
Classic studies by Lehrman and others have repeatedly demonstrated that hormonal condition can be regulated by social context and social cues. This social regulation of hormones or other neuromodulators allows males and females to coordinate the timing of reproductive behaviors. By attending to the sexual signals of their partners, males and females also orchestrate the timing of reproductive physiology. In a separate but related line of study, it is also well described that females choose mates based on what Darwin described as the females' sexual aesthetic. In this case, the female selects males with spectacular songs, colors, or odors because these traits match perceptual biases in her sensory system. However, female perceptual biases can by modified by her physiological state. So, if physiological state can be modified by social context or reception of social cues, is it possible that simply sitting at a dawn or evening chorus and listening to singing males can modify the females' physiology in such a way that ultimately influences who she will select among her male suitors? If so, this indicates that social regulation of hormonal state (or other physiological conditions) becomes a component of how female mate choice decisions occur. Here, we will describe a type of positive feedback loop in which courting males may enhance their chances of attaining a female response just by continuing to display. We describe how social regulation of the female hormones or other neuromodulators may be an additional component of mate choice via sensory exploitation. Overall, such a positive feedback system would indicate that timing is everything with respect to mate choice decisions. Therefore, in mating competitions, if at first a courting male does not succeed, he should try, try again.

37-4 LYNCH, LM*; MCKENNA, ME; DUDGEON, JV; Washington University in St. Louis School of Medicine, Idaho State University, Center for Archaeology, Materials, and Applied Spectroscopy Center; *leigha.marie.lynch@gmail.com*
Living on the edge: ecology of the extinct Noble marten as determined by morphological and isotopic evidence
The end of the Pleistocene saw the extinction of many megafaunal taxa in North America as climate changed and habitats shifted. North American *Martes*, comprised of three species, was one of the few small-bodied clades to decline in taxonomic diversity entering the Holocene, with the extinction of the Noble marten, *?M. nobilis*. Using morphological and isotopic evidence, we sought to determine the ecology of the Noble marten in order to better understand the cause of its extinction. We quantified limb bone shape in *?M. nobilis* using 3D geometric morphometrics and compared this shape to that of the extant *M. americana* and *M. caurina*. To determine diet, we measured $\delta^{13}C$ values from the enamel and dentin of *?M. nobilis* collected from the same locality as the limb elements. We found that the Noble marten significantly differs in limb shape from both of the extant species and possesses a more robust morphology. This suggests that the taxon was less arboreal than the extant species. $\delta^{13}C$ values, adjusted with a 13‰ fractionation for diet, ranged between -24.19‰ and -20.37‰, indicating that the Noble marten was eating a mix of C3 and C4 plants and/or prey with this diet. The results of this study suggest that *?M. nobilis* lived within an ecotone between Pleistocene forests and grasslands. This is supported by the mix of woodland and plains taxa found at fossils sites with *?M. nobilis*. Ecotones are highly dynamic environments and often act as buffers for the adjacent communities. Within an ecotone, the Noble marten likely encountered more drastic habitat changes at the end of the Pleistocene than extant *Martes*, which are found entirely in forested habitats. Such habitat instability could then have resulted in the extinction of *?M. nobilis*.

5-2 LYNCH, J*; GAU, JF; SPONBERG, S; GRAVISH, N; University of California, San Diego, Georgia Institute of Technology; *jelynch@ucsd.edu*
Resonance Properties of Insect-Inspired Series-Elastic Flapping Wings
Flying insects are thought to achieve energy-efficient flapping flight by storing and releasing elastic energy in their muscles, tendons, and thorax. The dynamics and energy efficiency of this process depend on the insect anatomy and the aerodynamic forces experienced by the wing. However, despite significant investigation into the aerodynamics of flapping wings, the influence of elasticity and wing inertia on the dynamics and control of wing movements is relatively unexplored. We developed a dynamically-scaled robophysical experiment to study the resonance properties of flapping wing aerodynamics in the regime of insect flight (Reynolds number between $10^2 – 10^4$). We observed the steady-state behavior of an acrylic wing actuated in series with a cast silicone torsion spring, varying the elastic element stiffness over a 4-fold range, system inertia over a 3-fold range, flapping amplitude (10 – 64 deg), and frequency (0.5 – 4.1 Hz). Comparing our results to a simplified analytical model of the system with quasi-steady drag forces, we found that the model fits the observed resonance behavior within ± 10% at steady state, suggesting that unsteady aerodynamic phenomena have a weak influence on the steady state dynamics of flapping wings with elastic elements. These experiments indicate the importance of wing inertia, body elasticity, and muscle actuation dynamics towards minimizing energy expenditure in flapping wing flight and aerodynamic force control in insects.

121-5 LYONS, K*; WYNNE-EDWARDS, KE; Georgia Aquarium, University of Calgary; *klyons@georgiaaquarium.org*
Legacy PCB Contamination Negatively Impacts Osmoregulatory Biomarkers in Pregnant Stingrays and their Embryos
Elasmobranchs utilize a unique osmoregulatory strategy based on urea as the main osmolyte. Because this strategy is energetically expensive, perturbations to homeostasis, such as that presented by legacy polychlorinated biphenyl (PCB) exposure, may be detectable in osmoregulatory biomarkers. Multiple tissues were obtained from pregnant Round Stingrays (*Urobatis halleri*) and associated embryos over the course of a gestational cycle from two locations where both environmental concentrations and physiological response to PCB exposure differs between sites. Solutes (urea, TMAO, proteins) were quantified in matched pairs of maternal plasma and histotroph and activities of enzymes indirectly and directly related to urea synthesis were measured in maternal and embryonic liver tissue. Pregnant females from the reference site maintained stable plasma urea concentrations, whereas plasma urea declined over the course of pregnancy in females from the contaminated site. In addition, muscle protein content significantly declined in contaminant-exposed, but not reference, females, indicating a potential loss of substrate for urea formation. Embryonic enzymes involved in the urea cycle and protein processing were functional, in contrast to the hypothesis that internal gestation (matrotrophic histotrophy), would delay the developmental onset of embryonic osmoregulation. While embryos were able to maintain urea and TMAO concentrations comparable to reference embryos, their liver protein content also significantly decreased over development, suggesting that osmoregulatory costs were higher. Increased costs for osmoregulation join other physiological measures adversely affected by legacy PCB contamination in these stingrays.

86-5 LYONS, MP*; VON HOLLE, B; WEISHAMPEL, JF; University of Central Florida, Orlando, University of Central Florida, Orlando and National Science Foundation, Washington, DC; *marta.lyons@gmail.com*

Impacts of Climate and Flooding on Current and Future Sea Turtle Nest Survival in the Eastern United States

Beaches along the southeastern coast of the United States provide important nesting habitat for three species of sea turtle, *Chelonia mydas*, *Caretta caretta*, and *Dermochelys coriacea*. These nesting areas are increasingly threatened due to sea level rise, human shoreline development, and changing climate. Female sea turtles come on land to nest under a wide range of conditions with non-obvious, context-dependent environmental and historical cues dictating nest site preference. Though nesting occurs under a range of environmental conditions across latitudes, developing embryos are extremely sensitive to local climate and disturbance. We are modeling how climate during incubation as well as the location of a nest in relation to the high tide line, other nests, and human development impacts overall nest success. We are accomplishing this through using multiple decades of nest success and locality data from six National Parks that span the current latitudinal extent of United States Atlantic sea turtle nesting. Our results support that the number of eggs that successfully hatch and emerge from the nest is dependent on the temperature and precipitation during incubation as well as the presence of disturbances like nest flooding and depredation, with species level differences relating to physiological temperature tolerances and phenology. This work allows us to quantify the effectiveness of current management practices, like nest relocation and predator exclusion, while creating spatial forecasts for future nest success that take into account changes in sea level, climate, and storm surge flooding over the next century.

109-5 MACKESSY, SP; University of Northern Colorado; *stephen.mackessy@unco.edu*

A little variety goes a long way: Diversification of three-finger toxins in rear-fanged snake venoms

Rear-fanged snakes ("colubrids") include a remarkable diversity of species that are found more broadly distributed than any other group of snakes, in part because of venom systems that are proving to be very diverse variants of a familiar theme. Among snake venoms, the three-finger toxins (3FTxs) are one of the better known families, with highly conserved structural scaffolds that supports a myriad of pharmacologies. For example, -neurotoxins are potent blockers of motor endplate acetylcholine receptors, but structurally similar molecules are used by plethodontid salamanders in courtship and in limb regeneration. Snakes in the Asian genus *Boiga* produce numerous 3FTxs, and some of them, such as irditoxin, are dominant venom components with taxon-specific and potent neurotoxic effects directed toward lizard prey. This motif is turning out to be common among the rear-fanged Colubridae – New World *Oxybelis* also shows this pattern, and we have recently characterized a lizard-specific dimeric 3FTx, with high homology with irditoxin, in the venom of *Spilotes sulfureus*,. Like *Boiga*, the venom gland transcriptome of *S. sulfureus*, formerly considered to lack a Duvernoy's venom gland, is dominated by 3FTxs, and the expressed venom consists of >92% 3FTxs, higher even than the vast majority of elapid venoms. However, in addition to a lizard-specific 3FTx, *S. sulfureus* venom also contains a mammal-specific monomeric neurotoxin, sulmotoxin, which is non-toxic to lizards. This is a unique toxin among 3FTxs and snake venoms generally, and it illustrates further the extent to which selection has favored diversification of a single toxin scaffold among snake venoms. Our results clearly demonstrate that a diversity of novel structural and functional variants of familiar toxins exist among rear-fanged colubrids.

48-7 MACK, JM*; DE CARLE, D; KVIST, S; University of Toronto, Royal Ontario Museum, University of Maryland, College Park, University of Toronto, Royal Ontario Museum; *joemack@umd.edu*

Prey, Populations, and the Pleistocene: Evidence for Low COI Variation in a Widespread North American Leech

Geographically widespread and morphologically diverse species typically exhibit limited gene flow, poor dispersal abilities, and cryptic diversity. The leech *Placobdella rugosa*, long a challenging organism to classify, represents an exception. Recent molecular analyses revealed a surprising lack of genetic variation among morphologically disparate, geographically widespread specimens of *P. rugosa*. Given the lack of any obvious mechanism by which this species could disperse between distant habitats, it was expected that widespread populations would be genetically isolated from each other. In the present study, we investigate the relationship between geographic distance and genetic diversity in *P. rugosa* using COI sequences from specimens collected across Canada and the United States. Although we find preliminary evidence for a barrier to gene flow between eastern and western collecting localities, our vastly expanded dataset largely corroborates prior studies, showing minimal phylogeographic signal among the sequences and negligible levels of genetic isolation by distance. A recent range expansion following the last ice age and/or host-mediated dispersal are discussed as potential explanations for this unexpected phylogeographic pattern.

24-7 MACKNIGHT, NJ*; DIMOS, BA; BRANDT, M; MULLER, E; MYDLARZ, L; The University of Texas at Arlington, The University of Virgin Islands, Mote Marine Laboratory; *nicholas.macknight@uta.edu*

The species-specific and shared immune competence of seven Caribbean coral when exposed to white plague disease

Intraspecies and interspecies immune competence was captured in seven Caribbean coral after laboratory-controlled exposure to white plague disease. A spectrum of phenotypic disease susceptibility differentiated the species and provided the backbone for identifying unique or shared gene expression profiles across species. Gene expression profiles were correlated to disease phenotypes, including lesion growth rate using WGCNA networks. 100% of *Orbicella faveolata* contracted the disease, showing significant expression of calmodulin binding and metalloendopeptidase regulation. 0% of *Montastrea cavernosa* contracted white plague disease and has significant changes in the expression of G-protein coupled receptors and developmental processes. The remaining species, which did not have all of their fragments contract the disease, offer species-specific insight on the gene expression that is unique in fragments that contracted the disease versus fragments of the same species that were exposed but did not contract the disease. The intermediately susceptible *Siderastrea siderea* had 60% disease prevalence by the end of the study and presented significant enrichment of caspases and inhibition of transforming growth factor-beta in fragments that were exposed but did not contract the disease. By identifying the gene regulation that drives the immune competence of these species, better predictions on future species composition and abundance can be made for Caribbean reefs.

S11-2 MACLEAN, E*; GNANADESIKAN, G; BRAY, E; SNYDER-MACKLER, N; University of Arizona, Arizona State University; *evanmaclean@email.arizona.edu*

Dog Diversity as a Natural Experiment in Cognitive Evolution

Dogs were once written off as a highly artificial species with little to contribute to the scientific study of behavior, cognition, or evolution. However, across the last two decades there has been a resurgence of scientific interest in dogs, in fields ranging from cognitive science to genetics. I will present a series of studies probing diversity in cognitive processes in dogs, considering patterns of variation at both the breed and individual level. Using a combination of pedigree-based and molecular genetics approaches, we find that a large proportion of variance in diverse cognitive measures is attributable to genetic factors. I will present ongoing work aimed at identifying specific genetic variants associated with variance in these cognitive phenotypes and discuss the implications of this work for understanding the processes of cognitive evolution.

140-6 MACRANDER, J*; SACHKOVA, M; SURM, J; LEACH, W; KETCHUM, R; REITZEL, A; MORAN, Y; Florida Southern College, University of Bergen, Hebrew University of Jerusalem, University of North Carolina at Charlotte, Hebrew University of Jerusalem; *jmacrander@flsouthern.edu*

A Multi-omic Approach to Evaluate Environmental Influence and Population Dynamics of Venom Production in Nematostella vectensis

The estuarine sea anemone *Nematostella vectensis* has emerged as a model organism to study the dynamic interactions between cell specific venom composition, development specific venom composition, and the impact of varied toxins on their biological targets. Within nearshore dynamic estuarine mud flats and temporary pools *N. vectensis* are apex predators feeding on a variety of invertebrate and potentially vertebrate prey as adults, however, their position as apex predators is a drastic shift from when they had to use their venom to defend themselves against predators as mobile planulae larvae. The complexity of these interactions may be further influenced by abiotic factors the predators encounter in these different environments as it relates to their geographical location. Here we report the differential gene expression patterns of *N. vectensis* when subjected to stressful environmental conditions and evaluate the potential role regional adaptations have on changes in venom gene expression. Additionally, we evaluate venom composition with a fine scale analysis using targeted MiSeq analysis of their key toxin protein and contrast this diversity with potential prey abundance using COI DNA barcoding. These approaches are further complemented by the use of comparative transcriptomics to identify strong overall population structure which correlates with toxin gene diversity. Our combined multi-omic analyses further highlights the usefulness of *N. vectensis* to address evolutionary and ecological questions as it relates to dynamic interactions between this complex venomous animal and its varied environment.

43-7 MADELAIRE, CB*; BARSOTTI, AMG; WAGENER, C; SUGANO, Y; BAXTER-GILBERT, J; GOMES, FR; MEASEY, J; Northern Arizona University, University of São Paulo, Stellenbosch University , Stellenbosch University; *cmadelaire@yahoo.com.br*

Invasive toads shift behavioral traits to find water

The adaptive nature of invasive species is becoming recognized as facilitating their survival in conditions that differ from their native range. Behavioral changes in invasive populations have been poorly explored but offer a wide potential when combined with physiological traits. For anurans invading xeric habitats, the importance of finding water is relevant for reproduction, to maintain hydration to function optimally and not experience dehydration stress. The water-finding hypothesis (WFH) states that survival can be enhanced through the behavioral ability to find water. We tested the WFH in *Sclerophrys gutturalis* from their native population in Durban and an invasive population in Cape Town Additionally, we tested if artificially elevated levels of corticosterone (CORT), which is known to increase during dehydration stress, affect water-finding behaviors. In a labyrinth experiment, we observed the toads' ability to find water in different hydration states (100%, 90% and 80%). We found that individuals from the invasive population took longer to engage in water-searching behavior and spent more time near to the water source after finding it. Also, toads from the invasive population were more active and at 90% dehydration they show higher number of attempts to find water. Moreover, elevation of CORT in fully hydrated toads increased the success of finding water. Our experiment suggests that rapid adaptative water-finding behavior might facilitates survival of an invasive anuran in a xeric habitat. Additionally, we suggest a link between elevated CORT levels and water finding success. Our results lend support to the importance of adaptive behavior in successful invasions and the modulation of water-finding behavior by CORT.

64-1 MAEDA, M*; WALKER, SM; FABIAN, JM; LIN, HT; BOMPHREY, RJ; Royal Veterinary College, University of Leeds, Imperial College London, Imperial College London; *mmaeda@rvc.ac.uk*

Aerodynamic and Structural Modelling and Simulation of Dragonfly Wing: Towards the Understanding of "Fly-by-Feel"

During flight, insect wings undergo large, periodic deformations on each cycle due to the inertial and aerodynamic loads they experience. Various studies over the last decade have shown that such deformations can have a significant impact on increasing aerodynamic force and/or reducing aerodynamic power, enhancing flight performance. It is therefore beneficial for a flying insect not only to detect and control its body attitude but its wing aeroelastic state as well. Strains that result from aeroelastic loads are detected by campaniform sensilla near the wing base, and a variety of flow sensors capture aerodynamic features on the wing. While the degree of sensory innervation varies drastically across the insects, this form of mechanosensory feedback has been shown to provide important information for the flight controller in some species. In this study, we aim to generate predictions of the strain field across dragonfly wings using fluid-structure interaction (FSI) numerical simulation, where computational fluid dynamics (CFD) and computational structural dynamics (CSD) are coupled. Towards that goal, we constructed dragonfly forewing and hindwing morphology models based on X-ray microtomography (micro-CT) scans. Dynamically deforming flapping wing models are reconstructed based on multiple-camera, high-speed recording of dragonfly flights. Preliminary findings from the CFD and CSD simulations are presented.

S1-6 MAHON, AR*; HALANYCH, KM; Central Michigan University, Auburn University; *mahon2a@cmich.edu*

Revisiting phylogeographic patterns in Antarctica in the age of '-omics.'

Antarctic fauna, particularly marine benthic invertebrates living on the continental shelf, are far more diverse than previously realized. Thanks to recent increases in sampling efforts, our understanding of Southern Ocean biodiversity has improved dramatically. In addition to increased sampling efforts around the continent, the application of molecular genetic and genomic tools to understand patterns of biodiversity is allowing us to understand and investigate entirely new patterns and processes from organisms in the Southern Ocean. Historically, studies employing mitochondrial genes or gene fragments (e.g., cytochrome c oxidase subunits I and II, 16S rDNA, cytochrome b) have found numerous unknown yet distinct genetic lineages in several invertebrate taxa isopods, sea spiders, echinoderms, and others. Despite this increased appreciation of diversity from the region, we are still trying to explain the bigger picture phylogeographic patterns around the Antarctic and the factors that produced such patterns. The development and application of new molecular methods on organisms from the region are allowing us to address questions relating to scenarios that may have impacted the current distributions of Antarctic shelf marine fauna using the resultant evolutionary patterns reconstructed from molecular data. These scenarios include a transantarctic seaway, Antarctic circumpolar current admixture, localized refugia, isolation by distance models, and other hypotheses. In this presentation, we will discuss our ongoing work that challenges major hypotheses related to the understanding of diversity in the Antarctic. As found in our previous studies, we expect that knowledge of organismal diversity through the implementation of additional 'omic studies will have tangential impacts throughout Antarctic biological research efforts.

13-5 MAINWARING, MC*; MARTIN, TE; WOLF, BO; TOBALSKE, BW; University of Montana, University of New Mexico; *mark.mainwaring@mso.umt.edu*

Nests reduce the energetic costs of brooding offspring for passerine birds in the tropics

Reproduction is an energetically expensive activity for parents and keeping endothermic offspring at their thermal optima represents a significant energy cost. Avian offspring develop optimally at ~39°C. The tropics are generally thought to provide warm ambient conditions that require less effort to keep offspring warm. Yet, the synergistic effects of high rainfall and winds that characterize the mid-montane tropics may exacerbate heat loss and mean that the energetic costs of keeping altricial offspring at optimal temperatures are substantially higher than previously imagined for the tropics. However, the building of enclosed and thus sheltered nests may enable birds to buffer the effects of adverse weather conditions. Here we provide experimental and observational evidence that ambient temperatures in the tropics are ~20°C below the thermal optima of 39°C and that rainfall and wind synergistically combine to increase the energetic costs of keeping offspring at thermal optima. Meanwhile, those costs varied between nest types, with species building enclosed nests saving significantly more energy than species building open nests. Our measurements and experiments demonstrated that rainfall, wind and their synergistic effect induces convective cooling that dramatically increases the costs of keeping endothermic offspring at their thermal optima in tropical regions. However, nest design can mitigate those costs and provide an important way of enabling animals to adapt to adverse environmental conditions in biodiversity-rich, but anthropogenically-threatened, tropical regions. (NSF: IOS: 1656120).

115-2 MAJORIS, JE*; FORETICH, MA; HU, Y; NICKLES, KR; DI PERSIA, CL; CHAPUT, R; SCHLATTER, E; WEBB, JF; PARIS, CB; BUSTON, PM; Boston University, Boston, MA and King Abdullah University of Science and Technology, Thuwal, Saudi Arabia, University of Miami, Miami, FL , University of Rhode Island, Kingston, RI and Boston College, Chestnut Hill, MA , University of Rhode Island, Kingston, RI , Boston University, Boston, MA; *j.e.majoris@gmail.com*

Neon Goby Larvae have Sufficiently Developed Sensory Systems and Swimming Abilities to Orient Directionally Beginning Shortly After Hatching

Though once considered passive particles, it is now widely recognized that late-stage reef fish larvae can detect and orient their movements in relation to olfactory, visual, and auditory cues. These behaviors have the potential to influence the emergent pattern of larval dispersal, with important consequences for marine population dynamics and conservation. Yet, little is known about when larvae develop the ability to orient their movement. In this study, we raised a coral reef fish, the neon goby *Elacatinus lori* , from hatch through settlement to investigate the development of their: i) sensory systems, ii) swimming abilities, and iii) orientation behaviors. Using a variety of anatomical techniques, we show that all of the major sensory organs are present and likely functional at hatch and their sensory organs increase in size, number, and/or structural complexity throughout the larval phase. Using a drifting behavioral arena (DISC), we show that larvae actively swim upon hatching and that swimming speeds increase throughout the larval phase. We also demonstrate that individual larvae orient directionally at all ages (2-30 days post hatch), providing compelling evidence that *E. lori* have the potential to influence their dispersal trajectory throughout the entire larval phase. Taken together, our results suggest that neon goby larvae may behave in ways that help to explain the relatively restricted pattern of dispersal for the species.

93-2 MALISCH, J/L*; HAHN, T/P; BREUNER, C/W; MALISCH, Jes; St Mary's College of Maryland, University of California, Davis, University of Montana ; *jlmalisch@smcm.edu*

Should I Stay Or Should I Go Now? Predictors of Facultative Altitudinal Migration in Mountain White-crowned Sparrows (Zonotrichia leucophrys oriantha)

Organisms that inhabit regions with high environmental variability must cope with sudden shifts in climatic conditions to survive and reproduce. In areas with steep elevation gradients, temporary movement from an area of high elevation to low elevation, facultative altitudinal migration (FAM), is a useful adaptation that promotes survival but may come at a cost to reproduction through the loss of territory or abandonment of a nest. White-crowned sparrows (*Zonotrichia leucophrys oriantha*) that reside in Tioga Pass Meadow, CA (elevation 3,030 m) are migratory and typically arrive in early May from their wintering grounds in Mexico. Snow cover is usually 100% and late spring snow storms are not uncommon. Furthermore, lower elevation refugia in the Mono Basin (~2,000 m elevation) are readily available. As such, this is a model population to investigate environmental and physiological variables that influence FAM behavior. Furthermore, this population has a relatively high rate of return allowing for an estimation of year to year survival. Here we review research on this single population spanning several decades and synthesize recent findings in a framework that includes environmental variables, physiological variables, and return rate in regard to FAM behavior. The physiological variables include glucose mobilization, glucocorticoid physiology and body condition. For FAM events that include corticosterone binding globulin measurements we will also discuss the difference between free corticosterone (CORT), total CORT, and bound CORT in reference to the Free Hormone Hypothesis, the Total Hormone Hypothesis and the Reservoir Hypothesis.

14-1 MANAFZADEH, AR*; KAMBIC, RE; GATESY, SM; Brown Univ., Johns Hopkins Univ.; *armita@brown.edu*
How informative is joint mobility? A 3-D analysis of potential versus realized joint poses in archosaurs
Paleontologists have traditionally reconstructed the locomotion of dinosaurs and other extinct animals by manipulating their fossil bones and inferring the mobilities of their limb joints. But even if we could estimate the ranges of motion (ROMs) of joints perfectly, are we justified in assuming that all of an animal's potential joint poses are exploited in life, let alone in locomotion? Here we evaluate the predictive power of joint mobility by determining what portion of a joint's full passive ROM is actually used during various behaviors. We measured the passive joint ROMs of the hip, knee, and ankle of the helmeted guineafowl (*Numida meleagris*) and the American alligator (*Alligator mississippiensis*) based on manipulations of fully intact cadavers. We then measured thousands of poses used at each of these joints during locomotor and non-locomotor behaviors using XROMM, and plotted the mobilities and poses on a common ROM map in 3-D joint pose space. We found that in all the joints studied, steady forward locomotor poses form a small and uncentered subset of all possible joint poses. The centroid of each joint's mobility -- sometimes termed the joint's "neutral pose" and thought to reflect habitual stance -- has no relationship to posture or locomotion. Rather, locomotor poses often fall along the edges of cadaveric ROM envelopes in 3-D joint pose space. These results suggest that even well-estimated joint ROM, though critical for the elimination of impossible joint poses, is a poor predictor of the locomotor poses actually used by extinct ornithodirans such as non-avian dinosaurs and pterosaurs. Future analyses of hindlimb joint surface interactions during life are necessary to further constrain paleontological reconstructions of locomotion.

57-2 MANEY, DL; Emory University; *dmaney@emory.edu*
Evolution of alternative behavioral phenotypes: A story of genes and bird brains
Disruptive natural selection can drive the evolution of alternative phenotypes, or "morphs", within one or both sexes. The morphs, so named because they differ with respect to a morphological trait such as coloration, often differ also with respect to behaviors such as courtship, territoriality, and parenting. In white-throated sparrows (*Zonotrichia albicollis*), birds of the white stripe (WS) morph engage in a more territorial, competitive strategy, whereas birds of the tan stripe (TS) morph assume a more parental strategy. These alternative phenotypes are genetically fixed in that they segregate with a chromosomal rearrangement present only in the WS birds. The rearrangement, or "supergene", contains differentiated genes known to contribute to territoriality and parenting, making this species an excellent model for studying how changes in gene sequence can ultimately cause changes in behavior. In this talk I will present highlights from our research in which we combine the fields of genomics, molecular biology, neuroscience, and field endocrinology to understand the evolution of behavioral phenotypes.

139-3 MANTILLA, DC*; TUCKER, EL; HSIEH, ST; Temple University, Philadelphia, PA; *dcmantilla@temple.edu*
Sand specialists and Non-specialists use Similar Kinematic Strategies for Running on Incline Granular Media
In the wild, animals encounter substrates varying in material properties and orientation. Feet have been shown to be more sensitive to changes in substrate properties by displaying posture and resilience adjustments on level granular and solid substrates. However, little is known about legged locomotion on inclined granular substrates, such as sand dunes, which fluidize with every step. It would therefore be reasonable to expect sand specialists to have kinematic adaptations for running on granular substrates, and fluid specialists to run well on sand due to its fluidizing properties. Previous results show that although running speeds are similar on the level granular substrate, sand specialist lizards consistently run faster than both generalist and fluid specialist lizards on the incline, with fluid specialists performing the most poorly. Here, we quantify how the kinematics differ among species and between surface angles. We ran a sand specialist (*Callisaurus draconoides*), a fluid specialist (*Basiliscus vittatus*), and a generalist (*Crotaphytus collaris*) along a level and incline (31°) fluidizable bed trackway. Lizards were filmed at 500 fps (Photron SA-3), and videos were analyzed in MATLAB. All three species similarly decreased impact speed on the incline compared to the level (P

112-2 MARBACH, S*; XU, W; Texas A&M University Corpus Christi, Corpus Christi, TX; *smarbach211@gmail.com*
The Toxic Effects of Nanoplastic Particles on Fish Embryonic Development
Plastic pollution is a globally recognized environmental threat that poses potential toxic effects on human- and aquatic organisms. Micro- and nanoplastic particles, which originate from various sources, such as clothing fibers, plastic production, and degraded plastic pollutants, have been of scientific interest in the past decades due to their characteristics of bioaccumulation in a wide variety of marine animals and their ever-increasing global distribution in aquatic environments. In this study, we investigate accumulation of nanoplastics (NPs) in fish embryo and the toxic effects on fish embryonic development using zebrafish *(Danio rerio)* as a model. Within 6 hours post fertilization (hpf), the zebrafish embryos were cultured in water solutions of fluorescent amine-modified polystyrene latex beads with concentrations of of 1μg/mL, 10μg/mL, and 100μg/mL. The development of embryos and the accumulation of the NPs in the embryos were monitored under a fluorescent microscope at 16, 32, and 48 hpf. Mortalities were recorded to obtain and analyze the toxicity and possible LD50 values of NPs. Additionally, genetic responses of the zebrafish embryos to the NP toxic effects were analyzed using quantitative PCR (qPCR). The bioaccumulating rates of NPs in zebrafish embryos at different concentrations were also calculated by monitoring the NP concentrations at 16, 32, and 48 hpf. The result of the present study will help to address the concern of NP contamination in water and the potential impacts to the aquatic animal health. It also contribute to the mechanistic study in the host immune response to NP toxicities.

123-3 MARCE-NOGUE, J*; LIU, J; University at Buffalo; *liujuan@buffalo.edu*

Testing an Isometric Ontogenetic Model for Vibrations of Weberian Ossicles in Zebrafish

Weberian apparatus (WA), known to enhance hearing in otophysan fishes, conduct sound vibrations through coupling of the gas bladder and inner ear. WA of the zebrafish are well developed with four pair of ossicles, and present diverse morphotypes in laboratory settings, and thus provide a great platform to understand the conductive hearing system of vertebrates. A key question is whether an isometric growth model (IM) can explain observed hearing capability of zebrafish through ontogeny. Here we present the first study to model isometric WA growth in zebrafish. We scanned an adult zebrafish using uCT (4.67 um/voxel) and reconstructed the WA digitally at its original size (OM, length of the ossicular chain (Lwoc) 2.6 mm). We then generated an IM series allowing size to vary from 1 to 10 mm in Lwoc. To evaluate their biomechanical performance, we performed harmonic analyses using Finite Element Analysis. The results show that the OM of WA predicts the expected amplitude and phase of the vibration. Second, analyses of the IM series result in proportional increase of bone displacement in each ossicle and a constant amplitude factor (ratio of amplitude of the first and last ossicles) with increasing size. Results from the OM suggest that the WA acts as a spring-transmitter at audible frequencies, permitting a coupling of gas bladder motion to the saccule. Furthermore, the IM could explain observed audiogram in actual zebrafish ontogenetic sequences. These findings suggest that the functionality of WA could be weakly influenced by allometric changes in ossicles chain morphology through zebrafish ontogeny. This model has potential to further elucidate whether the WA in different otophysan species of varied WA morphologies and sizes are comparable in terms of biomechanical performance.

55-6 MARKS, JR*; SORLIN, MV; LAILVAUX, SP; SCHWARTZ, TS; BEATTY, AE; University of New Orleans; *jrmarks@uno.edu*

Effect of Diet Restriction on Insulin-like Growth Factor 1 and 2 Expression in Female Green Anoles (Anolis carolinensis)

The insulin and insulin-like signaling (IIS) network is an important mediator of growth and metabolism in response to environmental conditions and is conserved across all animal taxa. Although the two main ILS hormones, insulin-like growth factor 1 (IGF-1) and insulin-like growth factor 2 (IGF-2), appear to mediate the trade-off between growth and reproduction, they have been studied primarily in mammals and their individual roles in other taxa, such as reptiles, are only vaguely characterized. Indeed, most studies on IGF have been performed in rodents, which do not express IGF-2 postnatally; and while fluctuations of IGF-1 in response to nutrient availability have received most attention, the responsiveness of IGF-2 to different environmental conditions has never been explicitly tested. We imposed a dietary restriction regime on green anole (*Anolis carolinensis*) females to test the hypothesis that IGF-1 and IGF-2 expression respond differently to dietary restriction. Specifically, we predicted that IGF-1 expression would be downregulated in diet restricted animals relative to controls, as is the case in other reptiles, whereas IGF-2 expression would be unaffected by dietary restriction. We discuss our results within the greater context of the IIS network as a lynchpin pathway for life-histories, and the potential for differential IGF expression to facilitate adaptive plasticity and maternal effects.

73-6 MARSHALL, CD*; RALEY, LN; PEREDO, CM; PYENSON, ND; Texas A&M University, Portland State University, University of Michigan, Smithsonian Institution; *marshalc@tamug.edu*

Implications for The Antiquity of Raptorial Biting in Pinnipedimorphs: Exploring Mandible Morphology in the Callorhinus Lineage

The integration of morphology and feeding performance studies can address questions relevant to feeding ecology and evolution. Pinnipeds are a major mammalian lineage with functional innovations for aquatic feeding. Recent functional data show that northern fur seals (*Callorhinus ursinus*) exclusively use a raptorial biting mode with the greatest gape angle opening velocity reported to date. It appears they are not capable of suction feeding, which is an unusual behavioral trait among extant pinnipeds. Furthermore, northern fur seals are considered to be the most basal living otariid pinniped. The *Callorhinus* lineage includes several extinct species and due to the craniodental morphological continuum of this lineage, they appear to retain their ancestral otariid feeding mode. We ask, is the feeding mode of *Callorhinus* indicative of deeper, ancestral feeding behavior among stem pinnipeds? Using 2D geometric morphometrics, we compared the shape of twenty-two fossil stem and crown pinniped mandibles. Sixteen homologous landmarks were digitized using the package Stereomorph in R. Function was then inferred from extant otariid performance studies to stem pinnipeds. Principle Components and Canonical Variates Analyses support the hypothesis that stem pinniped mandible shape does not differ significantly from extant *Callorhinus*. Therefore, stem pinnipeds likely employed the same raptorial feeding mode used by *Callorhinus* today, suggesting that *Callorhinus* retains the ancestral feeding mode through 25 million years of pinniped evolution.

36-3 MARSHALL, TL*; DAVIS, DR; HILLIS, DM; University of Texas at Austin, University of Texas Rio Grande Rio Grande Valley; *thomm80@utexas.edu*

Mitonuclear Discordance in the North American corn snakes (Pantherophis guttatus complex)

Mitochondrial markers have been widely used over the past 30 years to study phylogeography and infer species boundaries. The utility of these markers for such studies is based on the premise that variation within mitochondrial genes is largely neutral. However, evidence that different mitochondrial haplotypes within species confer differential fitness, and thus undergo selection, challenges this assumption. This, along with other factors, such as sex-biased dispersal and mitochondrial introgression across species, can lead to discordant genetic structure between mitochondrial and nuclear genomes. Mitonuclear discordance has been increasingly observed in a wide range of organisms, calling into question mitochondrial-based inferences of species boundaries. Here, we use a cytochrome-b sequence fragment and nuclear SNPs to investigate the presence of mitonuclear discordance in the North American corn snakes (Pantherophis guttatus), a complex that has been taxonomically defined by mitochondrial genetic structure. We identified five geographically partitioned mitochondrial haplotypes, indicating greater mitochondrial diversity than was previously recognized. However, only two of these haplotypes were monophyletic in our nuclear SNP phylogeny, which differed in topology from the mitochondrial tree. Further, population structure analyses using nuclear SNPs showed little evidence of reproductive barriers across haplotype boundaries.

106-6 MARSHALL, CA*; ZELLER, KR; GHALAMBOR, CK; Colorado State University; *Craig.Marshall@colostate.edu*
The Effects of Long- and Short-Term Salinity Acclimation on the Aerobic Scope of Trinidadian Guppies: Implications for Dispersal
Euryhaline fish species are able to tolerate a wide range of salinities. However, the extent to which fish populations cope with the energetic costs associated with fluctuating salinity levels through plasticity remains understudied. Moving from freshwater to brackish water should increase the minimum amount of energy required for basic physiological processes, or routine metabolic rate (RMR), and could decrease the maximum metabolic rate (MMR) if fish decrease gill permeability. An increase in RMR along with a decrease in MMR can result in an insufficient scope of activity, or aerobic scope (AS) to promote osmotic homeostasis. In Trinidad, the guppy (*Poecilia reticulata*) is confined to freshwater and behaviorally avoids brackish water, despite being considered euryhaline. To test if reduced AS contributes to the avoidance of brackish water, we conducted a common garden experiment that examined how long- and short-term acclimation to salinity altered AS. Wild-caught guppies were bred out to the second generation, and upon birth were split into either fresh- (0ppt) or saltwater (30ppt). RMR and MMR were measured, and AS was calculated in their rearing salinity to test long-term acclimation. We also used a gradual, step-wise acclimation to 5, 15, and 30ppt to test the effects of short-term acclimation. We predict AS should be maintained after long-term acclimation to saltwater, but should decline in response short-acclimation. Although the mechanisms of salinity acclimation are known in euryhaline fish, less is known about the potential trade-off between acclimation ability to salinity changes and other performance traits associated with fitness.

116-1 MARTIN, RJ*; KRUGER, MC; MACDOUGALL-SHACKLETON, SA; SHERRY, DF; Western University; *rmarti88@uwo.ca*
Temperature as a supplementary cue in the reproductive timing of the Black-capped chickadees (Poecile atricapillus)
Reliable environmental cues, such as photoperiod, allow birds to time their reproduction to match peak food abundance for their offspring. It is possible, however, that more variable local cues, like temperature, can provide more temporally precise information about the timing of these food events. Resident birds especially should be sensitive to temperature cues and use them to modulate their reproductive timing on a fine scale. We conducted two experiments to examine the effect of temperature on reproductive condition in a resident songbird, the black-capped chickadee, *Poecile atricapillus*. In the first experiment, we exposed birds to three over-winter temperature treatments under semi-natural conditions and assessed gonadal development in the spring. In the second experiment, we used a 2x2 factorial design to assess changes in gonadal development and circulating testosterone levels of birds experiencing different temperatures under photostimulatory and non-photostimulatory photoperiodic conditions. Temperature had no independent effect on gonadal development or testosterone levels, but when photostimulated, birds exposed to warmer conditions became reproductively ready earlier than birds experiencing cooler conditions. We conclude that temperature acts as a supplementary cue that aids birds in the timing of reproduction.

12-4 MARTIN, CM; University of California, Berkeley; *chmartin@berkeley.edu*
How to investigate the origins of novelty: insights gained from ecology, genomics, function, and fitness landscapes
Biologists are drawn to the most extraordinary adaptations in the natural world, i.e. evolutionary novelties, yet rarely do we understand the microevolutionary processes underlying the origins of novel traits, behaviors, or ecological niches. Here I discuss insights gained into the origins of novelty from my research program over the past decade on Caribbean pupfishes, spanning biological levels of organization from genotype to fitness landscape. I focus on a case study of the origins of novel trophic specialists on San Salvador Island, a sympatric radiation including the endemic scale-eating and mollusk-eating specialist pupfishes. I highlight questions that can be addressed about the origins of novelty at different biological levels, including the contributions of ecological opportunity, the isolation of novel phenotypes on the fitness landscape, the spatiotemporal origins of adaptive variation contributing to novelty, gene misregulation due to adaptive divergence, and form-function relationships for novel traits. Evolutionary novelties are rare, almost by definition, yet integrative case studies can provide insights into this rarity relative to more common adaptations, such as the relative isolation of novel phenotypes on fitness landscapes and the transient availability of ecological, genetic, and behavioral opportunities for novelty.

77-4 MARTIN, LM*; ESBAUGH, AJ; The University of Texas at Austin, Marine Science Institute; *leighann.martin@utexas.edu*
Recovery from catch-and-release angling in Gulf of Mexico fishes
The Gulf of Mexico's recreational fisheries has been estimated to provide in excess of $7 billion annually, and sportfish species like Atlantic tarpon (Megalops atlanticus) and red drum (Sciaenops ocellatus) are major contributors. Catch-and-Release (CAR) angling was implemented to help protect sportfish species, and the associated economic interests of stakeholders, yet the effectiveness of CAR can vary between species and ecosystems. Tarpon are unique among marine fishes because they can breathe air; however, their reliance on air breathing remains uncertain, which has important implications for CAR. As such, this study has two goals: 1) to determine if air-breathing behavior is facultative or obligate in tarpon, and 2) to assess the importance of air-breathing to recovery from exhaustive exercise. Juvenile tarpon were first observed via video for 1 h period in normoxia and hypoxia (20% oxygen saturation) to categorize air-breathing behavior. Consistent with facultative air-breathing, tarpon significantly elevated air-breathing rate when exposed to hypoxia. To simulate CAR events, individuals were chased to exhaustion and sampled, or allowed to recover for 1 or 4 h with or without access to the surface. A similar protocol was undertaken for red drum to provide a comparison to a non-air-breathing sportfish. Each individual was sampled for blood, white muscle, gills, and heart and assessed for a panel of common indices of exercise stress. Preliminary results suggest that tarpon begin to recover from exercise by 4 h post-exercise, with no clear benefits of having access to the surface. This was similar to the recovery profile exhibited by red drum. As such, no special considerations are needed in CAR procedures to accommodate the air-breathing physiology of tarpon.

16-6 MARTINE, C.T*; KELL, A. ; Bucknell University, Lewisburg, PA; *ctm015@bucknell.edu*
Cross-pollination: Art & Sex through the Lens of Botany
Offered as a sophomore-level Integrated Perspectives course at Bucknell University, Art & Sex Through the Lens Botany integrates the professional perspectives of a visual artist and a botanist into one course that seeks to impart the importance of making connections across disciplines and the value of visual literacy across academic lines. The course introduces foundational concepts in each field and encourages students to integrate these different systems of knowledge and to explore their intersections. We hope that our interdisciplinary approach to botany and to creating art will not only give students a new appreciation and understanding for each field, but also an awareness of the ways they can contribute meaningfully to cultural dialogue (including on topics in human sexuality) through the integration of science and art.

118-7 MARTINEZ, CM*; FRIEDMAN, ST; CORN, KA; LAROUCHE, O; PRICE, SA; WAINWRIGHT, PC; University of California, Davis, Clemson University; *cmimartinez@ucdavis.edu*
Large Mouths and Tapered Tails: Morphological Disparity Increases with Ocean Depth
Morphological traits comprising fish body plans can tell us a lot about how species interact with their surroundings. However, much of our understanding of the distribution of morphological disparity across habitats and environments is geographically constrained and taxonomically limited. In this study, we investigate body shape evolution and disparity at a global scale, as it occurs with increasing ocean depth, an environmental dimension along which many biologically important factors vary, including light, temperature, pressure, and nutrients. We make use of a large morphological dataset of ray-finned fishes, evaluating body shape disparity for over 3,000 marine species. Fishes were categorized into four traditional depth zones, epipelagic (0-200m), mesopelagic (200-1,000m), bathypelagic (1,000-4,000m), and abyssopelagic (4,000-6,000m). Using eight size-corrected linear traits, we show that morphological disparity increases more than two-fold across ocean depth zones. Body length and caudle peduncle traits had the greatest variance and elevated rates of evolution at depth. We observe that deep-sea fishes readily diversify along a body elongation axis, accessing the full range found at shallow depths in addition to novel elongate morphotypes. We also find greater jaw size (but lower variance and rate of evolution) with depth, a pattern that is frequently offered anecdotally, but has never been shown in a comparative study of this magnitude. The relative constraint on jaw size in aphotic, deeper waters is consistent with opportunistic trophic strategies. In contrast, the large variance in body elongation in the deep-sea may reflect a release from selective pressures on locomotion compared to light-dominated surface waters.

130-4 MASONJONES, HD; ROSE, E*; ELSON, J; University of Tampa, FL; *erose@ut.edu*
Nocturnal surveys of seahorses, Hippocampus erectus, reveal increased densities and seasonal recruitment patterns
Although the field of nighttime ecology remains understudied, nocturnal surveys can play an integral part in assessing fish assemblages. While little is known about seahorse nocturnal behaviors, congregations were documented at night in an isolated saltwater lake in the Bahamas. Population surveys for seahorses and their potential predators, octopus and crabs, were conducted in Sweetings Pond, Eleuthera, Bahamas, at midnight and midday during March and August 2018, using belt transects organized perpendicular to the shoreline and increasing in depth. Nocturnal surveys reported densities (1.2 seahorses/m-2) significantly higher than those reported on the same transects during the day (0.2 ind/m-2) and in previous studies in Sweetings Pond (0.14 ind/m-2). Predator densities followed a similar pattern with higher densities observed during the night. Sex ratios were consistently male-biased, and the frequencies of fish in different reproductive categories were significantly influenced by time of day. Daytime populations were made up of 70% males, with a high frequency of pregnant males in March, whereas nocturnal populations saw an increase in number of females observed. Seasonal recruitment was detected for the first time in this population, with an increase in juveniles detected in the shallow ends of transects during nocturnal surveys in March. Seahorses were also perched significantly higher in the water column during the night regardless of reproductive category, depth, or season. Considering *H. erectus* is listed on the IUCN Red List as Vulnerable, the drastic increase in population size due to changes in detectability, changes in sex-ratios, and presence of juveniles during nocturnal surveys has crucial implications for understanding their ecology and conservation.

134-2 MATHERNE, M*; HOWINGTON, O; LENAGHAN, O; HU, D.L; Georgia Tech Department of Mechanical Engineering, Georgia Tech Departments of Mechanical Engineering and Biology; *mmatherne3@gatech.edu*
The Effect of Nectar on the Honey Bee Pollen Pellet Removal Force
Honey bees (*Apis mellifera*) carry pollen back to their hive by mixing it with nectar and forming it into a pellet, which they carry in the corbicula, or pollen basket, on their hind legs. It is unknown how this method works across the range of sizes and shapes of pollen grains. In this study, we have filmed bees removing pollen pellets in the hive and conducted experiments to measure the force to remove them. We show that the more dried out the pellet is, the more force is required to remove it. We explain this difference in removal force using fluid mechanics principles. We also investigate the relationship between the amount of nectar in a pellet and the size and shape of the pollen grains. By studying the mechanics of pollen pellet formation, we hope to give insight into how honey bees are such effective pollinators.

107-4 MATOO, OB*; MONTOOTH, KL; University of Nebraska-Lincoln, Lincoln, NE, University of Nebraska- Lincoln, Lincoln, NE; *omatoo2@unl.edu*

Ethanol, Flies and Metabolism: Linking Genotypes to Phenotypes

Coincident with its out-of-Africa expansion, *Drosophila* also evolved capacity to live in ethanol-rich vineyards and orchards. However, sensitivity to alcohol varies among individuals within and across populations of *Drosophila*. Multiple genes and their interactions with the environment (G X E) underlie alcohol related fitness phenotypes. Furthermore, the bioenergetic responses to ethanol by mitochondrial oxidative phosphorylation (OXPHOS) require proteins from both the mitochondrial and nuclear genomes, creating the potential for inter-genomic gene-by gene (G X G, or epistasis) interactions to underlie variation in alcohol-induced phenotypes. Not surprisingly, therefore, the genetic bases of a complex trait like ethanol metabolism remains poorly understood. Here, we addressed this question by using *Drosophila* larvae with different nuclear and mitochondrial genetic backgrounds reared under developmental ethanol exposure. We demonstrated that ethanol induces oxidative stress, mitochondrial dysfunction (elevated basal respiration, proton leak, depolarization of mitochondrial membranes), and compromised whole-organism energy read-out (reduced lipid reserves and decreased pupation height). Thus, altered energy metabolism resulted in increased energy expenditure for basal maintenance in *Drosophila* larvae; but these effects were largely modulated by the underlying genetic architecture in both the natural isolates as well as in the larvae with mito-nuclear genotypes. These data correlate genetic variation with ethanol induced physiological trade-offs and provide comparative insights about how genetic variation among different ecotypes could potentially allow them to adapt to dynamic ethanol environments.

56-7 MATSUDA, SB*; CHAKRAVARTI, LJ; CUNNING, JR; VAN OPPEN, MJH; GATES, RD; Hawaii Institute of Marine Biology, Australian Institute of Marine Science, Shedd Aquarium; *shayle@hawaii.edu*

Coral (Acropora tenuis) background symbiont, Gerakladium>, competes with Durusdinium as dominant symbiont at elevated temperatures in multiple-genus symbiont-choice

Corals that take-up algal symbionts from the environment anew each generation (horizontal transmitters) may have a winnowing period during which specific symbiont associations become established from initially diverse infections, and this process could be modulated by the environment. *Acropora tenuis*, a common horizontal transmitting coral on the Great Barrier Reef, associates with a stress-sensitive species of *Cladocopium* and a stress-resistant species of *Durusdinium* as adults. We examined infection of *A. tenuis* larvae with four genera of Symbiodiniaceae with different thermal maxima (*Cladocopium*, *Durusdinium*, *Fugacium*, and *Gerakladium*) over two weeks at three different temperatures (27C, 30C, & 31C). Larvae were exposed to a single genus or an assortment of all four and individual larvae were flash frozen at days 3, 7 and 14. The type and number of symbionts/larva was measured in individual larvae by digital droplet PCR. All four genera were successful at initially infecting larvae at all temperatures in single infections and mixed infections. At 27C, *Durusdinium* was the dominant symbiont in 68% of larvae at day 3, and 79% at day 14. However, at 30C and 31C, larvae were dominated by either *Gerakladium* or *Durusdinium* at approximately equal frequency (approx. 40-43% each) by the end of the trials. *Fugacium*, which has the highest thermal maximum in culture, did not proliferate within the larvae at any temperature. If sea surface temperatures continue to warm during the onset of symbiosis, symbionts that were relatively rare or absent in *A. tenuis* adults, like *Gerakladium*, may begin to compete, which could have implications for holobiont performance under thermal stress.

4-2 MATTHEWS, DG*; DIAL, TR; LAUDER, GV; Harvard University; *davematthews@g.harvard.edu*

Suction feeding in zebrafish is improved by upregulated Wnt signaling

Among fishes, feeding mode is often considered the major axis of divergence and has been shown to produce extraordinarily rapid adaptive radiations. This behavioral evolution is often accompanied by a morphological shift in the craniofacial skeleton. One example of this can be found in the divergence between ecologically dissimilar species of cichlids from Lake Malawi, where the phenotypic novelty in the derived craniofacial morphology can be attributed in part to increased endogenous Wnt/ -catenin signaling. This developmental shift appears to be highly conserved as a similar morphological changes have been shown in zebrafish by increasing Wnt signaling. However, we have little idea how the resultant morphological shift is associated with functional variation. Here we experimentally manipulate Wnt expression in larval and juvenile zebrafish, then directly measure the resulting functional effects on suction feeding ability. We first use lithium chloride (LiCl) treatments to temporarily upregulate Wnt signaling at either three or fifteen days post-fertilization. We then raise these zebrafish to thirty days, the end of their larval period, and test their feeding performance using high-speed video to measure jaw kinematics and the flow velocity field. Finally, we compare morphological and kinematic variation between treated and control individuals. We find that zebrafish treated with LiCl can have improved feeding performance compared to the control fish. However, this effect depends on the age at which they received LiCl. Furthermore, there are differences in the craniofacial morphology and feeding strike kinematics in treated fish, suggesting that Wnt mediated morphological shifts can alter post-development feeding performance. This result gives us insight into the functional effects of rapid morphological shifts and therefore into the evolution of ecological novelty in fishes.

96-1 MATTHEWS, M*; CROWLEY, CJ; AIELLO, BR; SIKANDAR, UB; SPONBERG, S; Georgia Tech; *meganmatthews10@yahoo.com*

The Answer is Blowing in the Wind: Flower Wake Downwash Can Reduce Aerodynamic Forces in Insect Flight

Flying insects interact with changing aerial environments that may challenge aerodynamic performance. Both floral pollinators and the flowers they seek are affected by changes in airflow. Recent studies have begun to explore how animals alter behavior in response to unsteady air, but we do not know if these conditions represent the airflow behind natural flowers. Wind may blow from multiple directions and evidence suggests that flowers can re-orient to face downstream which means that pollinators would often fly through flower wakes. To investigate the features of a natural flower wake, we used 3D particle tracking velocimetry (3D-PTV) to measure the flow downstream of *Petunia* hybrids varying in diameter from 2-4.6 cm. The 3D wakes for all flowers showed an unsteady region of reduced wind velocity, comparable in size to the flower diameter, that extended 3-6 cm downstream. The unsteady region was present in all flower sizes, but we found that wakes of large flowers were dominated by a steady downwash. Flowers with d=4.6 cm induced a 10°-20° deflection of the freestream airflow that persists up to 2 cm above the petal height. Next, we determined the aerodynamic consequences of the steady induced wake angle for a hawkmoth hovering downstream with a blade-element model (BEM). At 0.7 m/s, a 20° difference in the incoming airflow results in a 9% loss in vertical force due to changes in effective angle of attack. During pollination, insects must reach the flower and maintain contact while interacting with the deflected flower wake, but the reduction in force suggests that animals would need to alter flight posture and/or kinematics to maintain performance, even at low wind speeds. Our work shows that flower wakes can incur significant losses in flight performance for pollinators.

S7-2 MAURO, AA*; GHALAMBOR, CK; MAURO, Alexander; Colorado State University; *amauro@colostate.edu*

The transcriptomic basis of a trade-off between salinity tolerance and competitive ability in the Trinidadian guppy

The factors determining the geographic distribution of organisms has long been of interest to organismal biologists. Eco-physiological studies have shown that what limits an organism's range in nature is not often one single factor, but rather the tolerance to multiple biotic/abiotic factors that vary across an organism's range. With the advent of modern genomic sequencing we can not only document the genes underlying environmental tolerance, but also the mechanistic basis for why they serve as evolutionary barriers to range expansion. Here we investigate the range limit of the Trinidadian guppy, *Poecilia reticulata* which is restricted to freshwater in Trinidad despite its ability to survive in brackish water in the lab and other parts of its range. Transplant experiments and behavioral studies show that salinity and competition with a closely related species, *Poecilia picta* , interact antagonistically to limit *P. reticulata's* range. This negative interaction is perhaps mediated by the fact that *P. reticulata* becomes subordinate to *P. picta* when in brackish water. In addition to documenting this interaction at the phenotypic level, we also investigated it at the transcriptomic level. We looked at transcriptome wide gene expression in the gills and brain of *P. reticulata* in different salinities and in different competitive environments to investigate if the negative phenotypic interaction is due to an antagonistic interaction between the transcriptomic responses underlying osmoregulation and aggression. Our genotype-to-phenotype approach can help to understand the complex pleiotropic trade-offs associated with different environmental challenges.

S9-1 MCBRAYER, L; MCELROY, E*; SUSTAITA, D; Georgia Southern University, College of Charleston, University of California at San Marcos; *mcelroye@cofc.edu*

Introduction: Applied Functional Biology: linking ecological morphology to conservation and management

A growing number of researchers work at the interface of organisms and their environment. Too often, academic scientists overlook insights that organismal, or functional, biologists can bring to the understanding of natural history, ecology, and conservation of species. Likewise, natural resource managers are frequently concerned with population sizes, while ignoring key functional traits that might explain fluctuations in population size. Our intention for this symposium is: 1) bring to light current and future research in functional and ecological morphology that also involve issues of concern to wildlife management and conservation, and 2) show how such studies can result in measurable outputs useful to regulatory agencies. Symposium topics will reveal past, present, and future collaborations between functional morphologists/biomechanists and conservation/wildlife biologists. Presenters will demonstrate specifically how data gathered to address fundamental academic questions regarding the causes and consequences of organismal form and function can also help address issues of conservation and wildlife management.

S9-7 MCBRAYER, LD*; ORTON, RW; NEEL, LK; KAUNERT, MD; TUCKER, DB; WILLIAMS, SC; Georgia Southern University, University of Texas Arlington, Arizona State University, Ohio University, Arizona State University; *lancemcbrayer@georgiasouthern.edu*

Integrating Studies of Function and Ecology to Inform Conservation and Management

The Ocala National Forest covers roughly 383,000 acres, 60% of which is critically threatened Florida scrub habitat. Florida Scrub is home to many threatened or endangered species such as the Red Cockaded Woodpecker, Florida Scrub Jay, Gopher Tortoise, Indigo Snake, Sand Skink and Florida Scrub Lizard. The Ocala National Forest is predominantly managed for timber and pulp industries via clear-cutting of sand pines on a 20 to 30 year schedule. Yet within the Ocala, seven long leaf pine sand hills are managed via periodic prescribed fires to ensure survival of certain threatened and endangered species. These contrasting management practices provide fertile ground for comparisons of the ecology and evolution of a variety of functional traits at the population level. I will present data from several studies to serve as a case study in how hypothesis driven functional biologists may work in such systems to the benefit of managers, conservation biologists, and basic scientists alike. This case study may also serve as an example of how junior faculty might establish a research program that serves multiple purposes. I will highlight initial work on foraging behavior and diet in the Florida Scrub Lizard that began to assess the effects of management practices. This work helped to frame subsequent studies on locomotion, population biology, predation, and physiology. Collectively, these studies allow managers to assess the impacts of management decisions on target (e.g. Red Cockaded Woodpecker) and non-target species (Florida Scrub Lizards). Recently, a new 20-year management plan was adopted such that past and future data will significantly inform the effectiveness of management practices, while also serving as an excellent system to test hypotheses on local adaptation and population level variation in functional traits.

25-3 MCCARTY, B*; MATTHEWS, M; SPONBERG, S; Georgia Institute of Technology; *bmccarty@gatech.edu*

Flexibility Maintains Leading-edge Vortex Structure on Manduca Wings

The leading-edge vortex (LEV) is a canonical aerodynamic mechanism in the flapping flight of insects, mammals, and birds across a variety of scales. While the *in vivo* LEV in insects is a coherent vortex that remains bound to the wing near the leading edge (with a diameter less than 50% the local chord length), in laboratory models with rigid wings this coherence is disrupted and the vortex grows (exceeding 80% the local chord length), a phenomena known as bursting. Bursting has been shown to reduce LEV lift, but it remains unknown how this impacts insect flight performance. Additionally, insect wing flexibility is known to increase lift. Its impact on vortex structure is unexplored, but its known role in force production suggests that flexibility distribution in insect wings could contribute to maintaining higher-lift unburst LEVs. To test this, we mounted freshly removed *Manduca sexta* wings on a motor rotating at a constant velocity to generate coherent LEVs at Re $O(10^3)$ and observed the fluid structure with smoke visualization. Freshly mounted wings consistently featured unburst LEVs, whereas desiccated wings (measured to be roughly twice the stiffness) created burst LEVs, suggesting that the compliance and flexibility gradient of insect wings contribute to the structure of LEVs. We next measured differences in local angle of attack between fresh and desiccated wings – fresh wings showed a near-linear increase in local angle of attack from root to tip, while desiccated wings featured a near-constant angle of attack outside of a sharp increase across the 40%-60% span region. Bursting occurs near the mid-span point on the wing where this sharp increase in angle of attack was observed. Combined, these results imply that the flexibility distribution of the fresh *Manduca* wing helps maintain LEV structure.

96-6 MCCASKEY, EN*; LEHNER, K; TAYLOR, I; BENFEY, PN; GOLDMAN, DI; Georgia Tech, Duke University; *emccaskey@gatech.edu*

Rice Root Tip Circumnutation Facilitates Exploratory Behavior

Circumnutation is the oscillatory movement of a variety of plant organs including roots. Little is known about the function of below-ground circumnutation, particularly in root-heterogeneity interactions. Root tip traits that allow for exploration may be advantageous, as roots can encounter heterogeneities in their environment that prevent productive growth. Previously we studied hard surface exploration in circumnutating wild type (WT) and non-circumnutating mutant rice roots using a high-throughput automated imaging system. In experiments with rigid plates containing holes embedded in a clear gel-based medium, we observed that a root coiling behavior in non-circumnutating mutant rice roots prevented effective root-surface exploration. WT roots had higher success in finding holes, enabling deeper growth. To reveal the sensitivity of these exploration dynamics to substrate parameters, in this work we use the gel-based media to create an environment consisting of two gel layers with varying stiffness. This environment can model soil horizons with varying compaction. Roots were grown in either a soft gel upper layer to a stiffer gel bottom layer, or the opposite. WT roots displayed less than 50% success in growing deeper in both treatments. When the roots did not penetrate the lower substrate, they grew along the gel interface, showing similar exploratory dynamics as in the rigid plate experiments. However, when non-circumnutating mutant roots grew from a stiff to soft gel layer, they had a 90% success rate in penetrating deeper compared to below 60% percent success from soft to stiff. Our data indicates that WT circumnutating root tips are sensitive to environmental heterogeneities such as changing soil compactness, and that circumnutation facilitates an exploratory behavior when such heterogeneities are encountered.

S1-1 MCCLINTOCK , JB*; AMSLER, CD; BAKER , B; MORAN , A; WOODS , HA ; University of Alabama at Birmingham , University of South Florida , University of Hawaii at Monoa, University of Montana ; *mcclinto@uab.edu*

Introduction to the Symposium: New Frontiers in Antarctic Marine Biology

The present symposium builds on three former SICB symposia that highlighted aspects of the marine biology of Antarctica, each taking place a decade apart, the first in 1988 and subsequent symposia in 2000 and 2010. In this fourth symposium, the term ‘New Frontiers' in the title is uniquely appropriate for two fundamental reasons. First, technological advances have greatly facilitated the advancement of polar science over recent years. And second, unprecedented global climate change has both dramatically impacted Antarctic marine biological systems, and rendered the coastal and offshore waters of the Southern Ocean a global model for the study of the biological impacts of warming and ocean acidification. Just as the eleven studies presented in this symposium highlight a new generation of Antarctic marine biologists, they similarly highlight how technological advances and climate change are influencing new frontiers in Antarctic marine biogeography, chemical ecology, physiological adaptation, microbial ecology, planktonic systems, and fjord ecology. If there is one grand take-home message from this symposium it is the field of Antarctic Marine Biology is becoming increasingly relevant to sustaining our own global biology. This symposium is supported in large part by NSF award OPP-1925160 from the Antarctic Organisms and Ecosystems Program.

1-1 MCDONALD, MS*; COHEN, JH; PORTER, ML; University of Hawai'i at Mānoa, University of Delaware; *marisam7@hawaii.edu*

Evidence for Ultraviolet Vision in Larval Stomatopod Crustaceans

Stomatopod crustaceans are known for having one of the most complex visual systems in the animal kingdom. While the adults have 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 for 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 photoreceptor. However, recent evidence suggests that stomatopod larvae have the anatomical and molecular structures to support ultraviolet vision. Based on this, the visual physiology of stomatopod larvae was examined using electroretinogram recordings. This work was completed in summer 2019 at the Keys Marine Lab in Long Key, Florida on two species of larval stomatopods. Larvae were dark-adapted and the response of the eye to brief (75 ms) flashes of broadband ultraviolet (peak 330 nm), blue (peak 510 nm), and orange (peak 570 nm) light was recorded. Additional measurements of broadband blue and ultraviolet light were completed under chromatic adaptation with a dim orange light. While larvae were most sensitive to blue light, this chromatic adaptation revealed a secondary response to ultraviolet light, indicating that larvae have sensitivity to ultraviolet light that is higher than is predicted by visual pigment templates. This is some of the first physiological evidence for ultraviolet vision in larval stomatopods, and larval crustaceans more generally. This work is significant as UV vision assists in a variety of behaviors in other marine organisms, and may be important to stomatopod larval ecology.

98-3 MCDONNELL, A.J; MOORE, C.L; SCHUETTE, S. ; MARTINE, C.T*; Chicago Botanic Garden, Bucknell University, Lewisburg, PA, Western Pennsylvania Conservancy, Pittsburgh, PA; *ctm015@bucknell.edu*

A harbinger of good things to come in academic/non-academic partnerships: Population genomics and conservation of Erigenia bulbosa (Apiaceae) in Pennsylvania.

Erigenia bulbosa, perhaps better known as the harbinger-of-spring, is one of the earliest-blooming wildflowers in eastern North America. In Pennsylvania, *E. bulbosa* exhibits an east-west disjunct distribution where widespread western populations are contiguous with the Midwestern range and a handful of populations in the eastern part of the state are restricted to the lower Susquehanna River valley. The isolation of the eastern populations suggests a possible conservation concern for those plants, with an assumed higher risk of fluctuations in numbers of individuals and the potential for lower levels of genetic diversity. As a consequence, regulatory considerations have created confusion during the environmental review process and left the Pennsylvania Department of Conservation and Natural Resources in the difficult position of justifying regulations that vary by region. To better understand population dynamics of the species, botanists from Bucknell University and the Western Pennsylvania Conservancy are engaged in a collaborative effort to couple field-based assessments *E. bulbosa* with a population genomics approach. Using single nucleotide polymorphisms from throughout the genome obtained via genotyping by sequencing (GBS) methodology, we find support for isolation of the disjunct populations and expect that populations in the East will continue to be threatened by land use and development along the Susquehanna River valley. This project is an important example of the strength of academic and non-academic partnerships in fostering outcomes that inform conservation of rare and special taxa.

95-7 MCDONOUGH, CE*; PITNICK, S; DORUS, S; Syracuse University; *mcdonouce@gmail.com*
Molecular evolution and sex-biased expression of Drosophila melanogaster female reproductive tract tissues
For species with internal fertilization, the complex interactions between the female reproductive tract (FRT) and male ejaculate(s) are critical to fertility, influence intraspecific variation in reproductive outcomes, and contribute to reproductive barriers between species. In contrast to the extensively studied male traits of sperm and seminal fluid proteins, the FRT, and particularly the molecular relationships among the discrete tissues within this system, remains poorly characterized. In order to develop a more complete understanding of FRT contributions to ejaculate-female interactions, we have taken a systems-level approach to characterize the spatio-temporal transcriptome of the *Drosophila melanogaster* FRT. The FRT is composed of 5 tissues which have a combination of distinct and redundant functions such as ejaculate processing, sperm storage, ovulation, and oviposition. We identified gene expression signatures that distinguish the FRT tissues and provide molecular support for their specific physiologies and functions. We further found that genes with tissue-specific expression and secretion signal annotation were more rapidly evolving. The characteristics of these genes resemble those found in accessory gland proteins of male seminal fluid and thus are likely candidates for their female counterparts. We also examined the expression of sex-biased genes within the FRT. Although we did find support for a small number of somatic reproductive female-biased genes unexpectedly, the greater trend was for FRT enriched genes to be male-biased. We hypothesize that this expression pattern is indicative of a molecular and biochemical continuity between the male and female reproductive environments.

95-5 MCENTEE, M*; KRZYSZCZYK, E; FOROUGHIRAD, V; FRèRE, C; MANN, J; Georgetown University, Washington, DC, University of the Sunshine Coast, Queensland, Australia; *mhm95@georgetown.edu*
Fitness and mortality costs to females in a system with allied sexual coercion
Female Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) are subject to high costs of reproduction, both during consortships, in which they experience allied sexual coercion from males, and during lengthy periods of gestation and lactation. Male dolphins cooperate in alliances to herd and aggress on females in order to increase mating access. Females must meet the high energetic demands of prolonged maternal investment in each offspring; gestation is one year and lactation averages 4 years. Here, we examine the effects of allied sexual coercion and maternal investment on reproductive fitness and survival in Indo-pacific bottlenose dolphins in Shark Bay, Australia. Nearly 20% of adult females in this population never successfully raise a calf to weaning. Mean age of first birth is higher for reproductively unsuccessful females (17.5 years) than for successful females (13.3 years), indicating that condition at the onset of reproduction could influence reproductive trajectory ($t(36.5) = 4.5$, $p < 0.001$). Females who are reproductively unsuccessful spend more time with adult males at the onset of sexual maturity than successful females do, suggesting that unsuccessful females may be subject to increased costs of coercion (GLMM, $p < 0.001$). Additionally, reproductively unsuccessful females have shorter lifespans than successful females (2 (1)= 16.8, $p < 0.001$). Taken together, these findings indicate that females who fail to raise a calf to weaning are then subject to increased risk of harassment and coercion from males, reducing their ability to recover condition and ultimately increasing their risk of mortality.

103-6 MCENTIRE, KD*; POLJAN, M; VELA, S; THOMPSON, ML; BAUM, A; Trinity University, San Antonio; *kmcentir@trinity.edu*
Do I Match? Exploring Self-Awareness of Color for Background Matching in Texas Horned Lizards
Camouflage through background matching is a common anti-predator strategy. There are multiple evolutionary mechanisms that could result in accurate crypsis. First, animals that passively match their surroundings are more likely to survive a predator encounter and pass on their traits. Alternatively, animals in complex backgrounds could move to an area where they are less conspicuous. The second option implies the animal has some awareness of their own color. This concept has not been extensively explored. Texas Horned Lizards (*Phrynosoma cornutum*) are known to use color patterns for camouflage, but the evolutionary mechanism leading to this crypsis remains unknown. We are using a lab-based study to estimate the lizard's tendency to background match by placing individuals in an experimental tank with three background colors (black, brown, and white) then exposing them to a predator cue. By recording the amount of time they spend in each color patch and seeing if it changes in response to a predator cue, we can estimate their self-awareness of color and its use as an anti-predator strategy. As a secondary avenue, we created an agent-based model predicting the predation rate of *P. cornutum* following both mechanisms. Preliminary trials suggest the lizards do not actively background match but may take cue from their natal environment as the captive born juveniles tended to favor the lighter background matching the substrate they grew up with. The model suggests decreased predation rates with active background matching, but needs to be validated with additional studies. This information can inform ideal release locations for captive rearing and release programs.

139-6 MCGOWAN, CP*; SCHWANER, SJ; LIN, DC; University of Idaho, Washington State University; *cpmcgowan@uidaho.edu*
Muscle Dynamics During Hopping on Hard and Sandy Surfaces
Desert kangaroo rats (*D. deserti*) are soft sand specialists that rely on sand dunes to construct their burrows. However, throughout the territories in which they forage, kangaroo rats can experience a wide range of substrates and obstacles, including hard and soft sand, rocks, and dense shrubs. The mechanical demands of hopping on these different surfaces can vary greatly. When hopping on soft sand, mechanical energy is lost to the substrate as the sand shifts under the animals' feet. This energy must be replace by mechanical work generated by muscles. The goal of this study was to determine how the lateral gastrocnemius (LG), a large ankle extensor muscle, contributes to the additional work required for hopping on soft sand. We used sonomicrometry and tendon force buckles to quantify the mechanical output of the LG as kangaroo rats hopped on a custom-built rotary treadmill with hard and sandy surfaces. Preliminary results showed that there were no differences in gait timing between hard and sandy surfaces and the ankle extensors produced similar peak forces (hard: 9.96 +/- 0.77 N, sand: 9.45 +/- 1.13 N). However, due to a slight reduction in LG muscle strain, the net work developed by the LG tended to decrease when hopping on sand (0.93 +/- 0.25 mJ), relative to the hard surface (0.68 +/- 0.14 mJ). These unexpected preliminary results suggest at least two possibilities: 1) kangaroo rats use proximal muscles to replace the energy lost to the environment; 2) kangaroo rats do not loose energy when hopping on sand, but rather hopping mechanics are similar to hopping on hard surfaces.

60-1 MCINROE, BW*; BOLAS, T; KO, I; FULL, RJ; UC Berkeley; *bmcinroe@berkeley.edu*

Reconfigurable control modules enable rapid burrowing in a decapod crustacean

Animals have innovated a multitude of strategies to locomote over and in natural substrates. To develop principles of adaptive locomotion in complex, dynamic environments, we studied the Pacific Mole Crab (*Emerita analoga*), a decapod crustacean capable of multimodal locomotion in the highly dynamic intertidal zone. *E. analoga* uses five pairs of multifunctional appendages to burrow rapidly into saturated, flowable intertidal substrate. We hypothesize that these controllable components can be represented as simple models (templates) that can be recruited in series or parallel towards robust and adaptive burrowing. Using granular particle image velocimetry (PIV) and refractive index matched substrates, we identified a set of potential control modules used by *E. analoga* to manipulate and make ingress into wet substrates. To further reveal the structure of these burrowing control modules, we measured limb kinematics as a function of depth. We found that limb cycle frequency of the anteriorly excavating appendages decreased from 3.7 ± 0.2 Hz at penetration to 2.2 ± 0.2 Hz at submersion. However, when the uropods were restricted, limb cycle frequency of the same appendages remained almost constant from penetration (3.1 ± 0.1 Hz) to submersion (3.0 ± 0.3 Hz), suggesting compensation. Finally, we propose a set of simple terradynamic template models that provide insight into the control affordances of the burrowing modules. Our findings begin to elucidate the structure and robustness of the burrowing control modules employed by mole crabs and suggest bioinspired design and control principles that may enable new burrowing behaviors in legged robots.

113-4 MCKEE, AA*; SOTO, AP; CHEN, P; MCHENRY, MJ; University of California, Irvine; *amberle.mckee@gmail.com*

The role of vision and flow sensing in schooling behavior

We are interested in how schooling fish use visual and flow-sensitive lateral line inputs. We used rummynose tetras (*Hemmigrammus rhodostomus*), a small freshwater schooling fish, to examine schooling behavior in light and dim conditions both with and without the lateral line (by chemical treatment). We performed an automated kinematic analysis of video recordings to measure schooling metrics including the polar order, nearest neighbor distance, and swimming speed. We found that schooling behavior was indistinguishable between fish without a functional lateral line and the control group. These results suggest that schooling kinematics do not depend on flow sensing. However, long-duration recordings revealed that fish without a functioning lateral line do not school as frequently as control fish. Therefore, vision is sufficient to form and maintain a school, but flow stimuli influence whether groups of *H. rhodostomus* initiate schooling.

125-4 MCMAHON, E*; YOUATT, E; BRAITHWAITE, V; CAVIGELLI, S; The Pennsylvania State University, The Pennyslvania State University; *ekm5112@psu.edu*

Stability of behavioral traits and associated physiology

Within groups, many individuals maintain distinct behavioral phenotypes, or temperaments, with some being reliably more exploratory, social, aggressive, active, or bold than others. These temperaments can influence individual survival, reproductive success and offspring survival i.e. fitness. While research has been conducted on characterizing temperament traits among species, there is still little information on the underlying physiological mechanisms. The objective of this study was to determine the relative stability of multiple behavioral traits and identify underlying physiological profiles. To identify the five temperament categories discussed by Reale et al. (2007) we conducted five behavioral tests repeated 3 weeks apart in a sample of 54 Sprague-Dawley rats. We used the Novel Social Arena, Novel Object Arena, Partner Preference, Social Interaction and Resident Intruder tests. To measure stress physiology, we conducted an acute restraint test and measured glucocorticoid (CORT) responses. Innate immunity and basal CORT were measured during an 8-hour period after injecting rats with lipopolysaccharide. To measure adaptive immunity, rats were injected with keyhole limpet hemocyanin (KLH) and relative hindfoot swelling (RHS) measured in response to re-exposure 29 days later. Specific behaviors were correlated across time in similar tests suggesting stable temperaments. Lower levels of exploration, activity, and sociability were associated with higher CORT reactivity. Additionally, lower levels of exploration, boldness, and sociability were associated with higher RHS following KLH re-exposure. Our findings suggest that some temperaments are more consistent than others and that physiological mechanisms differ with each behavioral phenotype. This may account for differential temperament fitness across environments.

52-4 MCTERNAN, MR*; SEARS, MW; Clemson University; *mmctern@g.clemson.edu*

Thermal and hydric balance: how salamanders respond to interacting stressors

It remains unclear how strategies used by salamanders to maintain thermal and hydric balance vary in response to one another, and whether this relationship varies geographically. Behaviorally, salamanders cease activity once they dehydrate to a certain threshold (the water limit threshold). Likewise, they will cease activity when they perceive themselves as becoming too warm (the voluntary thermal maxima). The cessation of activity prevents lethal levels of dehydration or heat stress, but also limits potential activity. Salamanders in warmer environments compensate by increasing cutaneous resistance to water loss to remain active. In this study, we will characterize the relationship between thermal limits and water loss using *Plethodon metcalfi* collected along an elevational gradient. We will first address how dehydration stress affects thermal maxima by measuring the voluntary and critical thermal maxima of salamanders at various hydration states. Additionally, we will measure resistance to water loss to test whether thermal limits vary in relation to water tightness. We will then place salamanders into two different acclimation treatments—a warm and dry treatment versus a cool and wet one. Measurements on acclimated animals will allow us to assess the plasticity of these traits, and whether acclimation alters the relationship between them. A better understanding of how salamanders balance thermal and hydric stress may further elucidate the capacity of this group to survive in a warming climate.

61-4 MCWHORTER, TJ; University of Adelaide; *todd.mcwhorter@adelaide.edu.au*

The Karasov effect: functional studies of nutrient absorption in endotherms at the extreme

The capacity of animals to assimilate energy depends on both mechanisms of nutrient absorption and gastrointestinal morphology. Flying vertebrates must fuel high metabolic demands while minimizing mass of digesta and gut size. Small birds and bats have shorter small intestines, less small intestine nominal surface area, shorter digesta retention times, and rely to a greater extent on non-mediated paracellular nutrient absorption than similarly sized nonflying mammals. In this talk, I will focus on functional studies of water-soluble nutrient absorption in volant endotherms at the extreme: hummingbirds and migratory passerines. Hummingbirds have exceptionally high mass-specific metabolic rates, and more than 35 years ago Bill Karasov and Jared Diamond showed that they have the highest mediated glucose transport rate amongst vertebrates. In vitro techniques also indicated that passive permeability to glucose was very low. In later in vivo studies, we found that the passive permeability of hummingbird intestines to glucose is much higher than previously reported, suggesting that they must rely partly on passive, non-mediated nutrient absorption to meet their high metabolic demands. Passerine birds migrating long distances arrive at stopover sites to refuel having lost as much as 50% of their initial body mass, including losses to the gastrointestinal tract that may serve as a reservoir of protein catabolised for fuel during flight, and show delays of 2-3 days in regaining mass. We found that a small passerine newly arrived at a migratory stopover had increased paracellular nutrient absorption, which when combined with extended digesta retention time may thus allow these birds to maintain higher digestive efficiency during initial stages of refuelling while digestive organs are rebuilt.

49-2 MCWILLIAMS, S*; KARASOV, W; BAUCHINGER, U; University of Rhode Island, Kingston, RI, USA, University of Wisconsin, Madison, WI, USA, Jagellonian University, Krakow, Poland; *srmcwilliams@uri.edu*

Spare capacity and phenotypic flexibility in the digestive system of a migratory bird: defining the limits of animal design

Flexible phenotypes enable animals to live in changing environments and knowing the limits to and the required timescale for this flexibility provides insights into constraints on energy and nutrient intake, diet diversity, and niche width. We exposed white throated sparrows (Zonotrichia albicolis), yellow-rumped warblers (Setophaga coronata), and cedar waxwings (Bombycilla cedrorum) to experimentally manipulated ambient temperatures over different timescales, which forces endotherms such as birds to modify their food and energy intake as they maintain a constant body temperature. We then quantified the extent of phenotypic flexibility in the digestive system of this migratory bird (i.e., food intake, digestive efficiency, gut anatomy, retention time of digesta, rates of nutrient absorption) in response to both rapid and gradual increases in energy demand. Immediate spare capacity decreased from ca. 50% for birds acclimated to relatively benign temperatures to < 20% as birds approached their maximum sustainable energy intake. Ultimate spare capacity enabled an increase in feeding rate of ca. 126% as measured in birds acclimated for weeks at -29 C compared to +21 C. Increased gut size and not tissue-specific differences in nutrient uptake or changes in digestive efficiency or retention time were primarily responsible for this increase in capacity with energy demand, and this change required > 1-2 days. We conclude that the pace of change in digestive organ size may often constrain energy intake and for birds dictate the pace of their migration. Supported by NSF (IOS-0748349 to S.R.M.) and NSC Poland (2015/19/B/NZ8/01394 to U.B.)

S9-11 MEHTA, RS*; DALE, KE; University of California, Santa Cruz; *rmehta2@ucsc.edu*

Linking Fitness and Functional Roles Inside and Outside a Marine Protected Area Around Catalina Island

The effectiveness of Marine Protected Areas (MPAs) on the general health and conservation of single species, habitats, and community interactions is of great biological and recreational interest. However, the high species diversity of southern California kelp forests limits our ability to make general conclusions about MPA effectiveness across a variety of species. Since 2015, we have contributed to the efforts to understand the role of MPAs in kelp forest ecosystems by studying the connection between fitness traits and functional morphology related to feeding for the California moray, *Gymnothorax mordax* . We chose to compare morays in Blue Cavern Onshore State Marine Conservation Area, which prohibits the take of any species, to those morays living in nearby coves where recreational fishing is permitted. Overall, we found that morays within the MPA were longer, older, heavier, and found in higher densities. As a potential consequence of higher densities, morays within and outside the reserve had similar body conditions, and morays within the MPA exhibited lower growth rates than those outside the MPA. Although morays within the MPA had larger size-corrected vertical and horizontal gape distances, indicating the ability to eat larger prey, morays within the MPA had significantly fewer stomach contents and smaller prey in their stomachs than those outside. Our research efforts show that while the MPA is positively related with age, size, and density of California morays, the MPA may not necessarily increase the fitness of this benthic marine predator. Instead, conditions in the MPA appears to favor alternative feeding strategies, potentially due to morphological variation.

64-4 MEKDARA, PJ*; NASIMI, F; TYTELL, ED; Tufts University; *prasong.mekdara@tufts.edu*

Sensorimotor integration in the control of dorsal fin movements during swimming

Fish fins are highly flexible, which allows them to form complex shapes that can offer hydrodynamic performance benefits. The flexibility in their fins allow fish to be highly maneuverable, permitting behaviors such as obstacle avoidance, predator escape, and backwards swimming. Fins also serve a sensory role, with many sensory receptors embedded in the rays, but we know relatively little about how the sensory information affects the muscular control patterns. Our research focuses on the dorsal fin of bluegill sunfish, which has a soft posterior portion that functions during locomotion as a highly flexible control surface, and presumably also as a flow sensor. To quantify sensorimotor integration in the fin's movements, we recorded activity in the dorsal inclinator muscles with and without a lidocaine treatment that numbs the sensory receptors. We quantified activity in the inclinator muscles and in red axial muscle during steady swimming at a low and high flow tank speed in three conditions: before fin numbing treatment, during fin numbing with lidocaine, and after lidocaine wash-out. During normal steady swimming, fish activate their dorsal inclinator muscles to stiffen their fins to resist lateral bending of the soft dorsal fin caused by resistive fluid forces imposed by the water. Activity of the dorsal inclinator muscles was variable when the fins were numb, with increased duration in each fin burst cycle, likely stiffening the fin. Our study shows that fish use sensory feedback for precise fin control during normal steady swimming, but without normal sensory inputs, they tend to stiffen the fin to make it more robust to mechanical perturbations.

100-2 MELICHER, DM*; YOCUM, GD; RINEHART, RP; USDA ARS, Fargo, ND; *dacotahm@gmail.com*

Transcriptomic response to long-term storage under a fluctuting thermal regime in Drosophila melanogaster

Insect storage under fluctuating thermal regimes (FTR) increases longevity and maintains fecundity in many species. We assessed mortality of *Drosophila melanogaster* during long-term storage under FTR. At 20-day intervals females were collected and sequenced out to 100 days as well as cold and warm temperature controls. Mean longevity was approximately 7 times longer under FTR. After 60 days fertility in females drops significantly. We show the persistent, long term transcriptomic response to storage under FTR, focusing on metabolism, oxidative stress, modification of membrane fluidity, and anti-oxidant activity.

33-1 MENDEZ-NARVAEZ, J*; WARKENTIN, K; Boston University, Smithsonian Tropical Research Institute; *javier0620@gmail.com*

Nitrogen Excretion Plasticity and Reproductive Colonization of Land by Frogs: Multiple Strategies to Avoid Ammonia Toxicity

Ammonia excretion is cheap but requires water; excreting urea helps terrestrial vertebrates conserve water and avoid ammonia toxicity. The desiccation risk and waste-disposal problems created when frogs evolved terrestrial eggs offer opportunities to test the role of nitrogen (N) excretion plasticity in transitions to life on land. We hypothesize that terrestrial early life stages alter N-excretion in response to drying or high ammonia levels. We studied 3 frogs that independently evolved terrestrial development: gelatinous arboreal egg clutches of *Agalychnis callidryas* (*Ac*) and *Hyalinobatrachium fleischmanni* (*Hf*) and terrestrial foam nests of *Leptodactylus fragilis* (*Lf*). Dry conditions increased ammonia concentration in all 3 species. With extended terrestrial development, *Hf* embryos and tadpoles in *Lf* foam nests began excreting urea. In *Lf* this was crucial to avoid ammonia toxicity. We hypothesize these animals precociously upregulate the urea cycle enzymes CPS1 and Arginase; enzymatic analyses to date support Arginase upregulation in *Lf*. Urea was present in some *Ac* clutches at oviposition, but appears not to be synthesized by embryos. Still, ammonia remained surprisingly low in dry *Ac* clutches, well below toxic levels, suggesting an alternative pathway to avoid toxicity. Initial results suggest upregulation of glutamine synthesis by *Ac* embryos under dry conditions. Overall, our results suggest that terrestrial early life stages of frogs use different plastic mechanisms to avoid ammonia toxicity in different lineages.

29-4 MENDOZA, E*; OLBERDING, J/P; AZIZI, E; University of California, Irvine; *emendoz7@uci.edu*

Temperature dependence of elastic recoil mediated by a mechanical advantage latch

Changes in temperature alter muscle kinetics and these effects can be observed during whole-organism performance. Some organisms use elastic recoil, which is far less sensitive to temperature, to power thermally robust movements. However, some systems (e.g. frog jumping) remain sensitive to temperature despite well-documented utilization of elastic mechanisms. For jumping frogs, the latch controlling the storage and release of elastic energy arises, in part, through dynamic changes in mechanical advantage (MA). Here we use an *in-silico/in-vitro* muscle preparation to understand how changes in temperature affect the flow of energy from muscles to tendons, and ultimately to the body, in a system using an MA latch. We use an *in-vitro* preparation of the plantaris longus muscle-tendon unit (MTU) that interacts with an *in-silico* model of a limb with changing MA and a mass being accelerated through a real-time feedback controller. We quantify the amount of energy stored in and recovered from elastic structures and the additional contribution of direct muscle work after unlatching. As expected, colder MTUs take longer to develop force and overcome the MA latch. Additionally, warmer MTUs continue to develop force far beyond what is needed to overcome MA before the mass has reached an appreciable velocity, storing more energy in elastic structures. We also find that the contribution of direct muscle work after unlatching is substantial and increases significantly with temperature. Our results suggest that the degree of thermal robustness achieved by a spring actuated system depends strongly on the nature of the latch that mediates energy flow and the inertia of the mass being accelerated.

113-5 MHATRE, N; Western University; *natasha.mhatre@gmail.com*

Active amplification in tree cricket hearing

Model system choice can be arbitrary and yet has a profound effect on what is considered ‘textbook behavior'. Traditionally, field crickets have been the textbook model system in insect acoustic-communication research; in behavior, neurobiology, or indeed, sensory biophysics. Tree crickets are a very similar group that also use sound for mate attraction. My recent work on their auditory biophysics has not strayed phylogenetically far from the ‘textbook model'; I have only changed subfamilies from the Gryllinae to the Oecanthinae. Yet it turns out that tree cricket hearing is quite different. Field crickets use resonant mechanical tuning as a filter for conspecific sound and are mechanically linear. Tree cricket ears are very different: they are not mechanically tuned, instead they use a physiological mechanism that actively amplifies a selected range of frequencies. This amplification mechanism renders their hearing highly non-linear, and provides an unusual level of flexibility. For instance, their auditory sensitivity changes depending on the loudness of sound, and even in the presence of other sounds of different frequencies. The frequency selectivity of this amplification mechanism changes with temperature and it can even be turned ‘on' and ‘off' for extended periods of time. In my talk, I will describe some of the interesting biophysics and biomechanics that underlies this auditory system. But mainly I hope to highlight that tree-crickets are only one new model system, from a very diverse group of acoustically and seismically communicating invertebrates, all of which hold out great potential for further rewriting the textbook on communication systems.

76-5 MICHEL, KB*; BISHOP, PJ; CUFF, AC; ALLEN, V; HUTCHINSON, JR; Royal Vet College UK; *kmichel@rvc.ac.uk*
Skeletal kinematics and muscle function during locomotion in tinamou, Eudromia elegans
The archosaurs are a clade of reptiles that underwent repeated evolutionary acquisition of bipedality throughout their 250 million year history, including the most speciose lineage of bipeds, the birds. Studies of avian locomotion can therefore illuminate locomotor evolution in archosaurs, and the biomechanics of striding bipedalism in general. We collected synchronised marker-based XROMM (biplanar high speed X-ray video) and ground reaction force data to investigate locomotion in *Eudromia elegans* across a range of walking and running speeds. As palaeognaths, tinamous complement previous studies of other avian species, and can help assess the ancestral state for hindlimb form and function in crown-group birds. Our data show that tinamou use hindlimb kinematics that are largely comparable to those recorded in other species (e.g., guineafowl, ostrich), although some differences do exist, such as markedly greater long-axis rotation of the tibiotarsus. In order to better understand the underlying musculoskeletal mechanisms that control limb movement, we also synthesised our experimental data with a three-dimensional musculoskeletal model of the tinamou hindlimb. The model was based on anatomical dissections, iodine-contrasted micro-tomographic scans and measured segment inertial properties, and includes all the major muscles of the hindlimb. Feeding the experimentally recorded data into the model, we used inverse dynamics to estimate external joint moments, and static optimization to estimate muscle activation patterns during the stride cycle. Our preliminary simulations produced activation patterns consistent with experimental electromyography data, lending confidence to the use of these models for extinct archosaurian bipeds. Further simulation using dynamic optimization approaches will allow us to explore the importance of tendon stretch and recoil in birds during locomotion.

11-3 MICHELS, NO*; HRABIK, TR; MENSINGER, AF; University of Minnesota Duluth; *miche498@d.umn.edu*
To Flee or Not to Flee: A Comparison of Predator Avoidance Behaviors Under Varied Light and Predatory Conditions
The quantity and quality of information during predator-prey interactions is influenced by a variety of environmental factors, as well as sensory and locomotory abilities of the pair. Previous studies focus on one predator within the environment, but prey face many attackers. Mottled sculpin are a native benthic fish similar to the invasive round goby. The goal here is to determine if one prey species has an advantage avoiding predators and if this advantage is light and/or predator dependent. The effects of predation and light level on prey behavior were examined using two piscivores, burbot and/or smallmouth bass in a crossed design (2 burbot, 2 bass, and 1 of each) which preyed on round gobies or mottled sculpin. Trials were performed under natural light intensities and wavelength of downwelling light. The probability of detection for each prey species for either predator was not significantly different. Only 7% of the detected gobies were captured and 72% of the captured gobies were retained. Comparatively, 23% of detected mottled sculpins were captured with 93% being retained. Almost double the number of mottled sculpin were consumed than round gobies within the same period. Both prey species alternate between fleeing or remaining immobile. Fleeing appears to benefit round gobies via reducing predator detection, but also helps avoid pursuing and attacking predators. Mottled sculpin often remain immobile, but initiate flight responses when predators are in close proximity which greatly increases the chances of detection, pursuits, and attacks. Few studies have tested prey reactions under multiple predatory conditions, and it appears that avoidance strategies differ between predators and have a considerable impact on survival probability.

88-2 MIKEL-STITES, MR*; STAPLES, AE; MAREK, P; Virginia Tech; *mmikelst@vt.edu*
Hearing Better When Lopsided: Tympanal Asymmetry May Enhance Hearing in the Parasitoid Fly Ormia ochracea
Ormia ochracea is a parasitoid fly endemic to the Americas. Gravid females respond phonotactically to calls of their male *Gryllidae* cricket hosts. Surprisingly, *O. ochracea* can locate their hosts with an azimuthal precision of 2°— equal to that of humans — in spite of their small size, which should prohibit this level of precision because of fundamental constraints imposed by the physics of sound propagation (Mason *et al*., *Nature*, 2001). Miles *et al*. demonstrated that the fly's two tympanal membranes are mechanically coupled, which increases the interaural time delay (ITD) between the tympana, allowing the fly to resolve nanosecond time differences, and greatly increasing the precision with which she can locate her larval hosts (Miles *et al*., *J Acoust Soc Am*, 1995). Here, we present the first measurements documenting tympanal size asymmetry in *O. ochracea*. We measured 38 tympanal membranes in 19 specimens and found a mean asymmetry of 5.6% in tympanal area between the left and right sides. We hypothesized and then demonstrated mathematically that this slight asymmetry should provide an additional significant increase to *O. ochracea*'s sound localization abilities, beyond that provided by the mechanical coupling of the tympana. We introduced a tympanal size asymmetry into the mathematical model of hearing in *O. ochracea* provided by Miles *et al*. and showed that an asymmetry of just 5% can increase the ITD by an order of magnitude compared to the symmetric case, and can similarly significantly increase the interaural amplitude difference (IAD) in *O. ochracea*. The ITD and IAD are the two quantities used by the fly to determine its prey's azimuthal location. Thus, the small asymmetry present in tympanal sizes in the fly may provide a significant advantage in sound localization.

86-2 MIKUCKI, E*; BUCHANAN, J; JULICK, C; MONTOOTH, K; LOCKWOOD, B; University of Vermont, Vanderbilt University, University of Nebraska - Lincoln, University of Nebraska - Lincoln; *emikucki@uvm.edu*
The Effects of Winter Warming Stress on Metabolic Activity in Diapausing Pieris rapae Butterflies
Due to harsh environmental conditions and limited food availability, overwintering organisms are dependent on a store of energy reserves that consists mostly of lipids to sustain them until spring. To compensate for this limitation, metabolic activity of overwintering individuals is characteristically low. Winter warming poses potential threats to overwintering organisms as metabolic activity is expected to increase due to increases in biochemical reaction rates, which may cause organisms to deplete their energy stores more quickly. To better understand the effects of winter warming on metabolic activity, we used stop-flow respirometry to measure resting metabolic rate after winter warming exposures in diapausing *Pieris rapae* pupae. We report that warmed individuals had a higher respiratory quotient (i.e., the ratio of carbon dioxide produced to oxygen consumed) than did control individuals, indicating that they switched from using lipid reserves to other reserves such as carbohydrates and/or proteins during recovery from heat stress. We also measured metabolic rates in real time during exposure to winter warming conditions to characterize thermal reaction norms across a range of temperatures. As predicted, metabolic activity increased with increasing temperature. Because metabolic rates increased and pupae switched to metabolizing energy resources (i.e., carbohydrates and proteins) that are likely to be more limited and, our results indicate that winter warming may cause diapausing pupae to deplete energy reserves. This research provides insight into the physiological consequences of winter warming on diapausing insect species and how these organisms may respond as environmental temperatures continue to increase during the winter months.

S9-8 MILES, DB; Ohio University; *urosaurus@gmail.com*
Can morphology predict the conservation status of iguanian lizards?
The integrity of regional and local biological diversity is under siege as a result of an multiple anthropogenic threats. The conversion of habitats, such as rain forests, into agricultural ecosystems reduces the area available to support species populations. In addition, fragmentation of the remaining habitats may render the environments unsuitable for survival or reproduction of species. Rising temperatures and altered rainfall patterns lead to additional challenges for species. The ability of conservation biologists to ascertain the threats to a species requires data on changes in distribution, abundance, life history and ecology. The IUCN uses these data to assess the a risk status for species. However, to date only 105,700 species have been assessed. Many species remain data deficient or yet to be assessed. In this study I ask whether a readily available database can be used to predict a species risk status. Morphological traits are an ideal proxy for making inferences about a species ecology. Past studies have shown that morphology can predict habitat use, foraging behavior and physiological performance among species. Here, I tested whether the patterns of covariation in 15 morphological traits can predict the risk status of over 400 species of lizards in the infraorder Iguania. I summarized the patterns of covariation using a Principal components analysis. Results from a phylogenetic ANOVA revealed that Vulnerable, Threatened, and Endangered species were larger, differed in body width and leg length as well as jaw length. A classification analysis confirmed the trends obtained with the PCA scores. I used the classification function to make predictions for species that had not yet been assessed by the IUCN species specialists groups. Because of the functional link between morphology, performance, and ecology, an ecomorphological approach may be a useful tool for rapid assessment of data deficient species.

S3-2 MILLER, CT; University of California, Berkeley; *ctmiller@berkeley.edu*
Developmental Genetic Analysis of Tooth Number Variation in Sticklebacks
Patterning of the dentition varies widely across different vertebrates, typically reflecting adaptations to diet. To begin to understand the developmental and genetic basis of evolved differences in dental patterning, we have been using the threespine stickleback (*Gasterosteus aculeatus*) system. Ancestral marine sticklebacks have repeatedly evolved major increases in tooth number in derived freshwater populations, likely reflecting shifts in diet to larger prey in freshwater environments. The increases in tooth number in multiple freshwater populations occur late during development, and are associated with an increased tooth replacement rate. We have used genome-wide linkage mapping to identify the genetic basis of evolved differences in tooth patterning. We mapped one genomic region controlling evolved increases in tooth number to an intronic tooth enhancer of the *Bone Morphogenetic Protein 6* gene. Ongoing work seeks to further determine the genetic circuitry that regulates tooth patterning, to understand how cis-regulatory changes affect tooth replacement, and to identify specific cell populations involved in tooth formation and replacement. Our genetic studies support the hypothesis that tooth replacement is regulated by homologous genetic circuitry that regulates mammalian hair regeneration, suggesting that an ancient genetic network regulates regeneration of multiple vertebrate epithelial appendages.

S7-8 MILLIGAN-MYHRE, KCA; University of Alaska Anchorage; *kmillig1@alaska.edu*
Using an evolutionary model organism to reveal host genetic influence on host-microbe interactions
Interactions between hosts and their microbiota involve multiple host systems and complex signaling between microbiota members. These interactions are balanced by host factors, including the immune system, hormones, diet, and more, and microbiota community interactions, both between members and between the microbiota and the host. When this balance is disrupted, the microbiota community shifts and the host often develops inflammatory or developmental diseases. Disruption can be caused by a combination of genetic or environmental factors. To determine the role of host genes in the ability of the microbiota to stimulate host immune responses and development, we adapted the evolutionary model threespine stickleback (Gasterosteus aculeatus). We characterized the microbiota in wild populations and determined that the host selects for and against specific members of the environmental microbiome based on their genetic background. We isolated over 300 microbes and created mock communities that reflect the microbiota identified by sequencing. We also manipulated the microbiota in developing fish from three different populations, and quantified immune system, somatic, and behavioral development in treated and untreated fish. We found that populations that shared ancestors but have evolved in different microbial and environmental conditions have different developmental trajectories when their microbiota is disrupted. These combined results indicate that populations are selecting for individual microbes, and may vary in their abilities to regulate microbial membership and response to microbes based on their genetic background.

83-4 MILLION, KM*; PROFFITT, MR; REESE, SJ; Indiana University, Bloomington, Howard University; *millionk@iu.edu*
MHC-based Olfactory Signals and Mate Choice in Darters (Etheostoma)
Genes of the Major Histocompatibility Complex (MHC) have been implicated in mate choice in a wide range of vertebrate taxa, with females of many species tending to prefer mates with MHC genotypes dissimilar to one's own. However, this preference has not been observed in all taxa studied, and the factors that influence MHC-based mate choice in vertebrates is still an open question. We hypothesized that differing reproductive behaviors between species may affect whether females make MHC-based mate choices and what their preferences may be. We tested this hypothesis using two co-occurring species of Darters (small North American native fish) with differing reproductive behaviors. In Fantail Darters (Etheostoma flabellare), males provide parental care, while in Rainbow Darters (Etheostoma caeruleum) no parental care is provided. We performed mate choice experiments in which we presented females of both species with pairs of identical painted male models along with olfactory stimuli from live males with differing MHC genotypes, one with an MHC genotype similar to the focal individual's and one with a dissimilar genotype. We measured the focal individuals' preference for the males using the amount of time the individual spent in each of two preference zones. Our early results indicate that female E. flabellare tend to prefer the scent of males with a similar MHC genotype while E. caeruleum females are split in their preferences, and the strength of preference differs between the species. We are currently evaluating our follow-up experiment testing whether females of either species prefer males with rare or common MHC genotypes within their local populations. Our research will provide insight into whether female MHC-mediated mate choice is influenced by differing reproductive behaviors and differing criteria for mates.

15-7 MIN, Y*; BALLERINI, ES; KRAMER, EM; Harvard University, Cambridge, MA, Sacramento State University, Sacramento, CA; *yamin@g.harvard.edu*

Understanding Floral Meristem Termination by Exploring Genetic Architecture Underlying Stamen Whorl Numbers in Aquilegia

Plants have the ability to generate new leaves continuously throughout their entire lifespan due to the persistent activity of stem cells in their vegetative meristems. During the reproductive phase, the floral meristem (FM) produces all floral organ primordia in sequential whorls or spirals. Unlike the vegetative meristem, the stem cell activity of FMs will always terminate at a specific time point during primordia initiation, since each flower only has a finite number of organs. Variation in the timing of FM termination (FMT) is an essential source of generating floral morphological diversity, but how this process is fine-tuned at a developmental and evolutionary level is still poorly understood. *Aquilegia* is a well-suited system for investigating this fundamental process, since flowers from different *Aquilegia* species have identical numbers of all floral organs except for stamens. Therefore, the variation in the timing of FMT can be represented by the variation of stamen whorl numbers in the flowers. We generated a F2 population by crossing *A. canadensis* and *A. brevistyla*, which are sister species with mean stamen whorl numbers of 9.15 and 7.16 per flower, respectively, and performed quantitative trait loci (QTL) mapping. We have phenotyped 4265 flowers for their stamen whorl numbers and conducted whole genome sequencing in 364 F2 individuals. Initial mapping revealed five major QTLs that are responsible for an estimate of 48% variation in stamen whorl numbers. Fine-mapping is currently in progress and we will be conducting functional studies of promising candidate genes. This is the first study to investigate the nature of variation in the timing of FMT, and our results will provide critical insight into how floral morphological diversity is generated at the meristematic level.

16-5 MINEO, PM*; HEBERT, AK; BENNETT, KF; GUENTHER, MF; KSIAZEK-MIKENAS, K; RAIMONDI, SL; Elmhurst College; *Patrick.Mineo@Elmhurst.edu*

Implementing Vision and Change into the first-year biology sequence for majors.

The Department of Biology at Elmhurst College recently revised the introductory biology sequence for first-year students following the recommendations of *Vision and Change in Undergraduate Biology Education* (AAAS, 2011). To align our course learning outcomes with these recommendations, we adopted a new textbook, *Integrating Concepts in Biology*, designed based on the core concepts and competencies outlined in Vision and Change. The classroom in this course sequence is largely "flipped", in which students complete in-depth learning objective homework before class, and spend class time analyzing the results of experiments connected to "Big Ideas" outlined in the textbook. In addition to a focus on scientific process, experimental design, and data analysis in the classroom, the laboratory component was transformed to include authentic research projects (Guenther et al. 2009). In this talk, I will discuss the structure of the course, as well as preliminary results of several assessments, including The Biology Concept Inventory (BCI), BIO-MAPS (designed to assess the core concepts and competencies of Vision and Change), and data indicating improved student outcomes and lower rates of students dropping, withdrawing or failing the courses. I will also share the successes and challenges encountered by both instructors and students in this course (especially in regards to achieving buy-in), as well as future directions.

128-4 MINICOZZI, MR*; AXLID, E; WILSON, T; BUCK, CL; VON HIPPEL, FA; Minnesota State University Mankato, Northern Arizona University; *Michael.Minicozzi@mnsu.edu*

Sodium perchlorate causes behavioral changes in developing zebrafish larva

Sodium perchlorate (NaClO4) is a strong oxidizing agent with a variety of military and industrial uses. Its widespread use and water solubility have made perchlorate a common contaminant of surface and ground waters across the United States. Perchlorate is an endocrine disruptor that inhibits thyroid hormone production. Here, we investigate the effects of sodium perchlorate on behavioral patterns in zebrafish (*Danio rerio*). Because behavior is tightly linked to brain development, a change in behavior of fish exposed to perchlorate could have important neurological implications for both humans and wildlife. We reared groups of 24 fish in three perchlorate concentrations (10ppm, 30ppm and 100ppm) and a control treatment (0ppm). At 5 and 10 days post-fertilization (dpf), we quantified their movements under three lighting conditions (lights on, lights off, and strobing) using a NOLDUS system. After conducting a principal components analysis, two major relationships were observed: at 5dpf, fish exposed to perchlorate moved significantly more under the lights on condition than did control fish. At 10dpf, fish in the control group moved more than did fish in any of the perchlorate-exposed groups under the lights off and strobing conditions. In both cases, the fish exposed to perchlorate showed a significant alteration in behavior as compared to the control group. The results from the 5dpf trial are especially notable because zebrafish normally show more activity in dark environments, and the observed behavior would likely make them more susceptible to predation under natural conditions. Further studies are necessary to determine the underlying mechanisms responsible for altered zebrafish behavior, and to examine the generalizability to other animals and people.

134-3 MITCHELL, CT*; DROTLEF, D; DAYAN, CB; SITTI, M; STARK, AY; Villanova University, Max Planck Institute; *cmitch23@villanova.edu*

Peeling the layers back: Examining the roles of capillary adhesion and material softening on gecko and gecko-inspired synthetic adhesive performance in variable temperature and humidity

The strong, yet reversible adhesive performance of geckos has been admired for many years. However, despite significant interest, there is still uncertainty about the governing adhesive mechanisms. For example, adhesive performance in variable temperature and humidity challenges two leading adhesion hypotheses: capillary adhesion and gecko setal softening. Both hypotheses consider variable relative humidity, but neither fully explain the interactive effects of temperature and humidity. Interestingly, gecko-inspired synthetic adhesives (GSAs) have shown similar adhesive performance in the same variable temperature and humidity environments. These GSAs represent a more controllable system that can be leveraged to test both hypotheses independently. Therefore, we conducted a comparative study between live geckos and GSAs in variable temperature and humidity to investigate the roles capillary adhesion and material softening have on gecko adhesion. In our gecko experiments, we identified an optimal range of environmental conditions for gecko adhesion. However, our GSA data remained relatively static across the same environmental conditions. This disparity in adhesive performances points towards both capillary adhesion and material softening playing significant roles in gecko adhesion, and only capillary adhesion affecting GSA adhesive performance. These results will help drive predictions into how geckos utilize various habitats, aid in the fabrication of new GSAs for robotics, biomedical, and commercial applications, and highlight an opportunity to use the gecko adhesive system as a model to explore an understudied area of basic surface science: temperature and humidity effects on micro and nanoscale systems.

63-3 MITCHEM, LM*; VILELLA-PACHECO, Z; FORMICA, VA; BRODIE III, ED; University of Virginia, University of Puerto Rico - Arecibo, Swarthmore College; *lm7en@virginia.edu*

Females Prefer to Associate with the Chemical Cues of Aggressive, Winning Males After Competition

Males often gain access to females by winning agonistic interactions, but females have the ultimate choice of who to mate with. We used *Bolitotherus cornutus* (forked fungus beetles) as a system to determine which behavioral traits are favored for male competition and if females prefer to associate with the chemical cues of winning males. In two separate experiments, we first observed male behaviors in dyadic competition trials. We found that relative body size and absolute aggression predicted whether a male emerged as a winner or loser. Our results support the large body of research showing that body and weapon size determine success in agonistic interactions. We also report here that initiation of aggression is important for winning agonistic interactions. In our second experiment, we placed females in arenas with filter papers containing chemical cues of two males and measured the time each female spent associated with the cue of either male. Next, we allowed the two males to interact and determined winners and losers. We then placed females in new preference trials following male-male interactions and measured the amount of time they spent on winning and losing male chemical cues. Females did not prefer to associate with either future winning or future losing males before male-male interaction but changed their preference to avoid losing males after male-male interaction. Taken together, our results indicate that male reproductive success in *B. cornutus* is driven by the outcomes of male competition. Larger, more aggressive males likely gain more opportunities to mate via winning competitions and female avoidance of losing males.

37-8 MIYASHITA, T*; GESS, RW; COATES, MI; University of Chicago, Chicago, IL, Albany Museum, Makhanda, South Africa; *tetsuto@uchicago.edu*

The Evolutionary Origin of the Filter-feeding Larval Phase in Lampreys

The ontogeny of lampreys holds a special place in the historical development of ideas about the early evolution of vertebrates. Ammocoete larvae of living lampreys (cephalochordate-like, sand-burrowing filter feeders) have served as a model for primitive vertebrates, whereas the eel-like, typically blood-sucking adults are considered specific to that lineage. This recapitulatory view of lamprey ontogeny has long predicted the last common ancestor of all living vertebrates to be an ammocoete-like filter feeder. If the Ammocoete Model is correct, a filter-feeding larval stage should have existed in lamprey stem taxa. We test this prediction using newly discovered specimens of *Priscomyzon riniensis* from the Devonian Witpoort Formation of South Africa. Seven specimens form an ontogenetic series from a 15 mm-long individual (slightly larger than living lamprey hatchlings) to an adult. None of these specimens has any skeletal correlates of filter feeding. Instead, traits associated with the predatory life mode of living adult lampreys are present in all of specimens, including: prominent eyes; oral sucker; keratinous teeth; tectal cartilages; short branchial region; and pericardial closure of branchial basket. Therefore, *Priscomyzon* likely had no ammocoate stage. To test whether the absence of the ammocoete stage is (a) a tip state unique to *Priscomyzon* or (b) a general condition of the lamprey stem, we compared three other Paleozoic stem lampreys (*Hardistiella*, *Mayomyzon*, and *Pipiscius*) with the *Priscomyzon* series. The smallest specimens of each taxon closely resemble the late larva to post-metamorphic juvenile stages in *Priscomyzon*, which implies that the ammocoete larval stage of living lampreys represents a secondarily evolved condition, convergent with cephalochordates due to feeding habits.

15-3 MONROE, JG*; MCKAY, JK; Max Planck Institute for Developmental Biology, Colorado State University; *greymonroe@gmail.com*

From satellites to sequences: investigating drought adaptive life history evolution in plants

Explaining variation in life history strategies has been a central challenge of ecology and organismal biology for at least 250 years. To test classic theory of drought as a driver of adaptive plant life history strategies, we have been integrating diverse data and approaches including satellite imagery, herbarium specimens, whole genome sequencing, and transgenic experiments. In this seminar, I present recent research on the ecology and functional genomics of drought adaptive life history evolution. First, we tested classic life history theory by integrating satellite based drought detection with herbaria occurrence records to study life history evolution at phylogenetic scales. By comparing historical drought regimens, we observed that annuals occur in environments where droughts are significantly more frequent. We also found evidence that annual plants adapt to predictable drought regimens by escaping drought prone seasons as seeds. In addition to macroevolutionary patterns of life history evolution, we were also interested to understand drought as a driver of intraspecific variation. Thus, we developed novel approaches to study natural loss-of-function alleles associated with drought histories. The genes we identified exhibit population genetic signatures of adaptive evolution and shared associations with flowering time phenotypes in directions consistent with longstanding adaptive hypotheses seven times more often than expected by chance. We then confirmed predicted phenotypes experimentally in transgenic knockout lines. This research has yielded valuable insight into the evolution of life history strategies; validating long standing theoretical predictions about drought as important agent of selection and also providing surprising results about the functional genomics of this evolution.

51-5 MOON, H*; ANDERSON, T; TRAVERS, M; LOEW, E; PORTER, M; University of Hawaii at Manoa, Kauai Endangered Seabird Recovery Project, Cornell University; *hmoon@hawaii.edu*

How Do Seabirds See Light? Visual sensitivity and light attraction in Hawaiian seabirds

Artificial lights at night cause high mortality in fledgling seabirds due to attraction and subsequent grounding. Seabirds species of concern on Kaua'i are the Hawaiian Petrel (*Pterodroma sandwichensis*), Newell's shearwater (*Puffinus newelli*), and the Wedge-tailed shearwater (*Ardenna pacifica*). *P. newelli* fledglings have the highest rates of light attraction on Kauai of all three species of concern, suggesting differences in behavior and/or vision between species as well as between fledglings and adults. Previous studies on migratory birds suggest that the color of light can affect attraction. To understand visual sensitivity, light color, and light attraction, the speed and strength of response of the retina to different colors of light was measured in all three species of concern. Seabirds attracted to light and rescued by Save Our Shearwaters were anesthetized, then retinal response to flashing LED lights was measured using electroretinography. Up to five different intensities of light were tested using three different colors of light- ultraviolet (385nm), blue (450nm), and white light (peak at 594nm). Seventeen juveniles representing all three species of concern and three adult *A. pacifica* were tested in the first year. Preliminary results suggest each species responds quickest to white light and slowest to UV light. *P. newelli* have the strongest response to blue light, and *A. pacifica* have the strongest response to white light, indicating interspecific differences in visual sensitivity. These results have implications for conservation management of artificial light near seabird colonies.

21-5 MORA, Y/A*; SUSTAITA, D; FARABAUGH, S/M; Department of Biological Sciences, California State University San Marcos, Institute for Conservation Research, San Diego Zoo Global; *mora074@cougars.csusm.edu*

Analysis of Loggerhead Shrike wing-flashing movements during hunting

The Loggerhead Shrike (*Lanius ludovicianus*) is a medium sized predatory, insectivorous and carnivorous songbird. When hunting, Loggerhead Shrikes have been observed to perform wing-flashing movements prior to attacking their prey. Several hypotheses have been proposed for this behavior in shrikes and other species. Our research focuses on the effect wing-flashing movements have on prey capture performance. We approached this by analyzing videos of captive San Clemente Loggerhead Shrikes during feeding. We found that males tended to perform wing flashing more than females, and juveniles tended to perform wing-flashing more often than adults. All of the individuals filmed performed wing-flashing when attacking lizards, whereas relatively fewer performed the behavior when attacking crickets and mice. The rate of wing movements varied among prey types, with crickets eliciting higher rates than lizards and mice. In general, shrikes captured their prey in fewer attempts after performing wing-flashing, suggesting that these wing movements increase prey-capture efficiency. A larger proportion of prey reacted to the onset of attack, and relatively fewer seemed to react to the wing-flashing behavior itself. However, prey capture success was greater when prey seemed to react to wing-flashing, suggesting a potential role for these wing movements in making prey more accessible. Our results point toward yet another innovative tool deployed by shrikes for accessing their diverse arthropod and vertebrate prey.

82-8 MORALES, OJ*; WALKER, N; WARNE, RW; BOYLES, JG; Southern Illinois University - Carbondale; *vincere90@gmail.com*

Consequences of pharmacologically induced corticosterone hormone on body temperature and body condition in the banner-tailed kangaroo rat.

Anthropogenic environmental change such as habitat fragmentation and climate change poses challenges to animal homeostatic functions due to its unpredictable nature. The hypothalamus-pituitary-adrenal (HPA) axis release corticosterone (CORT) to help maintain homeostasis, mobilize energy reserves, and promote immediate survival during times of stress. However, chronic exposure to environmental stressors may influence long term changes to animal body condition and thermoregulatory patterns in increasingly harsher habitats. The banner-tailed kangaroo rat is an ecosystem engineer and keystone species in the Chihuahuan desert. Its seed caching strategies and relatively large burrows contribute immensely to soil quality, moisture retainment, and vegetative diversity. Using corticosterone implants to mimic environmental stressors, we pharmacologically stressed banner-tailed kangaroo rats with CORT and control implants to assess changes to their body condition over a two-month period during the summer of 2019. We further measured body temperature, an easily measured proxy of energy expenditure, and body condition of another set of kangaroo rats in relation to pharmacologically induced stress to assess for differences in thermoregulation. Preliminary results suggest marginal differences in heterothermy among animals treated with CORT but no significant differences in fat, lean mass, or water content among treatments. Changes to fat content and lean mass was not significantly affected by treatment however there was a marginally significant interaction between time and fat content.

S9-12 MORAN, C J*; GIBB, A C; WARD, D L; The Citadel, Northern Arizona University, United States Geological Survey; *cmoran3@citadel.edu*

Integrating studies of anatomy, physiology and behavior into conservation of imperiled cyprinid fishes of the Southwestern United States

Cyprinid fishes endemic to the Southwest have been subject to anthropogenic pressures that caused many of these species to become threatened or endangered. The foremost pressures on these fishes are habitat modification through and the introduction of non-native competitors/predators. The prevailing management strategy for many of these fishes is captive breeding/rearing and release into altered habitats. However, captive-reared fish typically suffer low survival following release. We suggest that, by combining morphological, physiological and behavioral data, management agencies can improve the survival of repatriated fishes. Recent measures of performance metrics and behaviors of fish in the *Gila* sp. complex in the lab and in smaller waterways have generated specific predictions about success of individuals of particular body sizes under certain conditions. For example, *Gila* individuals below a certain size are more likely to be consumed by non-native predators, than individuals above a particular body size; therefore, the probability that re-introduced native fishes survive after they are placed in a waterway will increase with increasing body size. Similarly, higher water flows will favor the retention of *Gila* sp. (based on their swimming performance); this finding suggests that controlled flooding or a return to natural hydrologic conditions would aid in native fish recovery. We conclude that understanding performance metrics associated with anatomical and physiological adaptations can allow managers to manipulate habitats to better suit native fishes. Taking a whole ecosystem management approach allows managers to not only improve the success of native fishes but return native habitats to original conditions.

137-4 MORAN, C J*; HUDSON, D; GERRY, S P; The Citadel, Maritime Aquarium, Fairfield University; *cmoran3@citadel.edu*

Implications of muscle performance on the management of recreationally and commercially important fishes.

Many fisheries in the Northeastern United states are seasonal as cooling temperatures in the fall trigger many species to migrate offshore away from summer fishing grounds. Once established, the seasons of "open fishing" are difficult to change. By understanding the physiology of commercially and recreationally important species managers can make more informed decisions as to seasonal activity of these species. As a case study, we examined a series of performance metrics related to routine activities in a seasonally active species from New England. The overfished tautog (*Tautoga onitis*) make short migrations to offshore wintering habitats where they undergo winter dormancy. We analyzed muscle performance, feeding kinematics and the escape response at a range of relevant temperatures in order to establish a comprehensive view of how temperature impacts this species and its associated fishery. Based on the research we present here we can provide managers a more accurate picture as to how temperature and future climate warming will impact seasonal distribution and activity. Understanding the seasonality of fish behavior and physiology is integral in a management strategy.

53-3 MORENO, KR*; WEINBERG, M; YOVEL, Y; HARTEN, L; CZIRJáK, SL; SALINAS-RAMOS, VB; HERRERA MONTALVO, LG; Department of Zoology, Tel Aviv University, Tel Aviv, Israel, Leibniz Institute for Zoo and Wildlife Research, Berlin, Germany, Department of Agriculture, University of Naples Federico II, Naples, Italy, Institute for Biomedical Investigation, Universidad Nacional Autónoma de México, Mexico City, Mexico; *Kelsey.R.Moreno@gmail.com*

Sickness in Fruit Bats: Unique Immune Reaction Reflects a Unique Social Behavior

The immune response's first line of defense, the acute phase reaction, contributes to the early control of infections, yet little is known about its adaptations to successfully cope with bacterial infections, particularly in fruit bats. We investigated physiological and behavioral aspects of the acute phase response in the Egyptian fruit bat (*Rousettus aegyptiacus*) by injecting a bacterial Lipopolysaccharide (LPS) in comparison with a saline buffer (PBS) control. We tested 11 experimental animals and 10 control in a closed colony, then extended our findings' validity with 5 free ranging bats housed in our open colony. Bats were monitored via on-board trackers, video, weights, and blood draws. Experimental individuals displayed marked differences in food consumption, body weight, body temperature, movement, probability of exiting to forage, maximum distance traveled, total distance traveled, sociality, and Haptoglobin. These changes bear similarity to other known mammalian acute phase responses, but displayed a far more intensive amplitude. Such severity of response indicates strong reaction to bacterial infection; far different than the antiviral response found in this species and the reaction found in insectivorous bats. Moreover, because Egyptian fruit bats are highly social, their solitude sickness behavior is a clear deviation from the norm.

27-3 MORRIS, ZS*; PIERCE, SE; ABZHANOV, A; Museum of Comparative Zoology and Department of Organismic and Evolutionary Biology, Harvard University, Department of Life Sciences, Imperial College London; *zmorris@fas.harvard.edu*

Developmental mechanisms shaping crocodylian snouts

Crocodylian skull shape is tightly associated with dietary ecology. A continuum of snout lengths exists in living crocodylians, from short & blunt faces in the dwarf crocodile (*Osteolaemus tetraspis*) to dramatically elongated snouts in the tomistoma (*Tomistoma schlegelii*). The evolution and function of snout shape has been widely explored, but the developmental programs which underlie differences in snout length have yet to be revealed. Comparative developmental studies in birds and mammals (e.g., Darwin's finches and bats) have revealed facial elongation can be achieved by maintaining or increasing the rate of cell proliferation in the facial mesenchyme and/or delaying skeletal differentiation. Our previous work showed heterochrony was critical in the evolution of crocodylian skull ontogeny. We now aim to study cellular dynamics (cell proliferation and cycling) and gene expression at key developmental stages in three species with distinct snout lengths: *Alligator mississippiensis*, *O. tetraspis*, and *T. schlegelii*. Integrating *in ovo* EdU labeling with *in situ* hybridization allows us to assess if temporal and spatial shifts in the expression of genes controlling skeletogenesis can explain differences in cranial ontogeny. Our data show differences in proliferation rate at the tip of the snout can be detected at Ferguson stage 14, prior to differences in facial length. Our results so far suggest cell proliferation decreases earlier in the blunt-snouted species than species with longer faces and may be driven by differential deployment of genes controlling cartilage differentiation (e.g., Bmp4 or CaM).

8-4 MORRISON, E*; DECKARD, T; ADANIYA, K; DEMAS, G; Department of Biology and Center for the Integrative Study of Animal Behavior, Indiana University; *eam10@iu.edu*

Maternal gut dysbiosis via antibiotic administration affects the behavior of offspring Siberian hamsters (Phodopus sungorus)

The acquisition of microorganisms by a newborn mammal during birth and thereafter prime the infant gastrointestinal tract and may have both immediate and lasting effects throughout the lifespan of the offspring. The transfer of beneficial microorganisms from mother to infant is highly dependent on the condition of the maternal gut microbiome. Inadequate establishment of the infant gut microbiome has been linked to lasting health concerns, and dysbiosis within the adult gut microbiome via antibiotic administration has been linked to behavioral and physiological changes. Therefore, maternal intake of antibiotics during breastfeeding may alter the maternal gut microbiome and subsequently impact the offspring. We investigated the consequences of maternal antibiotic administration on behavior and physiology of both dams and offspring Siberian hamsters. Hamsters were given an oral dose of broad-spectrum antibiotic daily from parturition for one week. Offspring from these mothers were then raised to adulthood and mated. We show that maternal care was not directly affected by antibiotic administration. However, the offspring of antibiotic-administered mothers exhibited aberrant maternal behaviors toward their own offspring. Data on changes in the gut microbiome for all three generations and their relationship to adult behavior will be presented. Collectively, these findings provide insight on the intergenerational effects of maternal gut dysbiosis on physiological and behavioral responses of offspring.

15-1 MORRISON , CR*; SMILEY , J; The University of Texas at Austin , University of California San Diego; *crmorrison@utexas.edu*

Using a Portable Hydrogen Cyanide Gas Meter to Uncover a Dynamic Phytochemical Landscape

A major contributor to global biodiversity is the tremendously variable landscape of secondary metabolites characterizing organisms. Crushing or chewing leaves catalyzes a reaction that releases potentially toxic hydrogen cyanide gas (HCN) in over 3000 species of vascular plants representing 110 families of ferns, gymnosperms, monocotyledonous and dicotyledonous angiosperms. These include a diverse group of economically important crops such as cassava, stone fruits, lima beans, bamboo and cashews. Nearly all species of passion vines in the genus *Passiflora* (Passifloraceae) contain HCN-releasing cyanogenic glycosides. These compounds are key drivers of adaptive radiation in *Passiflora* and the highly specialized herbivorous insect taxa that consume them. The conventional method for quantifying cyanide concentration in *Passiflora*, and other biological samples, is the Lambert colorimetric procedure. This procedure can be prohibitive. It requires expensive analytical equipment, substantial investment of time in collecting and processing samples, and is restricted to laboratories that are often away from the field where study organisms occur. Here we present a new method for quantifying HCN concentration of biological samples that is cheap, flexible, efficient, and high throughput. This method is based on a simple apparatus assembled around a portable HCN meter developed for emergency personnel. An evaluation of the accuracy and validity of this method by comparison with the conventional Lambert procedure will be presented. We will conclude by taking this opportunity to showcase the utility of this method by presenting dynamic spatial and temporal patterns of HCN heterogeneity in tropical *Passiflora* that have been discovered using this technique.

110-7 MOSSOR, AM*; AUSTIN, BL; AVEY-ARROYO, JA; BUTCHER, MT; Youngstown State University, Sloth Sanctuary of Costa Rica; *ammossor@student.ysu.edu*

Are sloths horses hanging upside down?: Suspensory adaptations of sloth flexor tendons

Sloths are nearly obligatory in their use of suspensory locomotion and posture, and due to their low metabolic rate, body temperature, and rate of digestion, have an extreme need to conserve energy. It is possible that sloths possess a 'suspensory apparatus' analogous to that of upright ungulates, thus allowing for largely passive support of their body weight while minimizing muscle energy expenditure. The digital flexor tendons from the fore- and hindlimbs of two-toed (*Choloepus hoffmanni*) and three-toed (*Bradypus variegatus*) sloths were loaded in tension until failure with an Instron machine to test this hypothesis. Tendons displayed low tensile strength and Young's (elastic) modulus, but had moderate stiffness indicating some compromise between strain resistance and joint position control for grip strength. Sloth flexor tendons also had elevated safety factors for suspension involving multiple limb contacts. Overall, the tendon loading curves and material properties were similar to those of generalist mammals (e.g., rats) and also match well with those of equine suspensory 'ligaments.' These results help explain previous findings in sloths that show low levels of muscle activation in the digital flexors among other major forelimb flexors during suspensory walking and postural hanging. Current evaluations are focused on potential modifications of increased tensile strength in the long limb bones of sloths that further indicate mechanisms that permit suspensory habits in mammals.

111-3 MOUNTCASTLE, AM*; AHLHOLM, PD; STONE, I; FEDERICO, P; NIXON, E; JOHNSON, N; Bates College; *amountca@bates.edu*

Effects of wing size and wingbeat frequency on wing wear in bumblebees

Many flying insects frequently collide their wing tips with vegetation. Repeated collisions can cause the wings to wear down over time, which can reduce flight performance and increase the risk of mortality in bumblebees (and likely other insects as well). However, little is known about how wing size and wingbeat frequency – both correlated with body size – affect the rate of wing wear. To address this question, we used a high-speed motor to artificially induce damage in the wings of *Bombus impatiens* bumblebees by forcing them to repeatedly collide with a leaf surface 500,000 times. We spun wings from two different size groups (large and small) at two different speeds (fast and slow), to independently test the effects of wing size and wingbeat frequency. We found that the rate of wing wear depends on both wing size and rotational velocity, suggesting that insect wings may experience size-dependent selective pressures associated with collision-induced wing damage.

8-1 MRUZEK, JL*; DIMOS, B; MACKNIGHT, N; KATHRYN, C; BRANDT, M; MYDLARZ, LD; University of Texas at Arlington, University of the Virgin Islands ; *joseph.mruzek@mavs.uta.edu*

Linking Disease Resistance in Coral to its Ability to Maintain a Complex Microbiome

Caribbean coral reefs are threatened by disease, and the coral's microbiome, the complex community of microorganisms on the coral's surface, plays a critical role in both disease resistance and progression. The microbiome-disease relationship has been inferred solely through relative abundance and functional profiles of bacterial taxa, but here we go beyond these methods, presenting a look at the structure of the microbiome community. Utilizing co-occurrence networks, we measure the microbiome's connectance, the number of interspecific connections, and its modularity, or groupings of species. A complex microbial community is predicted to be more stable, allowing coral to better resist infection, thus we compare the network topology of the microbiome of two coral genera: *Porites*, shown to be resistant to white plague disease, and *Orbicella*, susceptible to white plague. As Porites is resistant, we predicted a more complex, more disturbance-resistant microbiome, than *Orbicella's* prior to exposure. We also predicted that disease resistant *Porites* would not have altered network topology following exposure, whereas the infected *Orbicella* would have a less connected and more modular microbiome. Prior to disease exposure, we did not find significant differences between the microbiome networks of *Porites* and *Orbicella*, rejecting our first hypothesis. After exposure, there is a significant decrease in connectance and increased modularity only in *Orbicella*, while *Porites* does not show significant changes in network topology, implying that the ability to maintain a structurally complex microbiome is linked to the ability to resist disease.

13-4 MUGEL, SG*; NAUG, D; Colorado State University; *smugel@colostate.edu*

Metabolic Rate Variation Shapes Pace of Life Traits at Both the Individual and the Group Level

Pace of Life (POL) models have recently emerged to integrate covariation among behavioral, physiological, and life history traits along a single fast-slow axis. Variation in metabolic rate, the fundamental biological rate at which organisms acquire, process, and expend energy, is often considered the primary driver of phenotypic covariation that defines POL at an organismal level. The metabolic theory of ecology however suggests that the functional importance of metabolic rate should also drive similar patterns at higher levels of organization, although such ideas have rarely been empirically investigated. Using honeybees (*Apis mellifera*) as an experimental model, we measured a number of behavioral, physiological, and life history traits at the individual and group level. We then adopted a structural equation modeling approach to present evidence of a POL in honeybees consistent with many of the theoretical predictions and the role of metabolic rate in shaping covariation structure. In order to explore similar patterns at the group level, we then bred genetic lines of honeybees with slow and fast metabolic rates based on the malate dehydrogenase locus and then created experimental groups that were homogenously slow, fast, intermediate, and heterogeneously mixed groups of slow and fast bees. We then assayed these groups on some of the same behavioral, physiological, and life history traits that were measured at the individual level as well as some additional group level traits, in resource rich and poor environments. Using a partitioning of variance approach on these trait values across different group compositions, we then investigated the relative selection (non-additive) and complementarity (additive) effects of metabolic rate and how they interact with the resource environment in shaping the pace of life at higher levels of biological organization.

102-4 MUHAMMAD, S*; DICK, MF; WELCH, KC; University of Toronto; *saad.muhammad@mail.utoronto.ca*

Sugar Flux and Metabolism in the Ruby-Throated Hummingbird.

Hummingbirds are one of two flying nectarivores that can uniquely use recently ingested fructose or glucose to power flight. Previous work in our lab suggests that for hummingbirds this could partly be due to muscle physiology having both glucose and fructose transporters, and high hexokinase activity. These may give the hummingbird an ability to metabolize native fructose directly in muscles, unlike other vertebrates. However, the observed hexokinase activity rate is not high enough to support flight direct oxidation in the muscle with fructose. Thus, it is unclear how hummingbirds maintain a high sugar flux, particularly for fructose, while hovering. First, we examined changes in plasma metabolites of fasted birds versus those fed sucrose (glucose and fructose). Our fasted birds showed blood fructose levels of 0.2mM whereas fed birds had around 5mM blood fructose levels. In contrast, blood glucose levels remain similar after one hour of fasting, suggesting fructose levels are much more dynamic than glucose levels in the blood. To explore the differential use of these sugars we examined sugar flux by comparing fed birds given glucose or fructose and fasted birds. Ruby-throated hummingbirds' metabolites were quantified from birds that were fasted, or fed glucose, or fructose. We used LC-MS based metabolomics to determine the metabolite concentrations in highly metabolic tissues (liver, heart, pectoralis muscle). Specifically, we were interested in central carbon metabolism which helped elucidate which pathways fructose and glucoses are using. In addition, relative amounts of glucose transporters and monocarboxylate transporters at the tissues provide support for metabolite data. We also show that the ruby-throated hummingbird has higher capability to use exogenous fructose via different metabolic pathways in tissues, like muscle, than that of mammals.

104-5 MULLER, U*; SUMMERS, AP; CSUF, UW - Friday Harbor Labs; *fishguy@uw.edu*

SICB Journals - synergy, status, and a call to action

Two journals are published by the Society for Integrative and Comparative Biology SICB: Integrative and Comparative Biology (ICB) and Integrative Organismal Biology (IOB). Both journals serve the SICB community by bringing scientific publishing into the 21st century. In over 50 years of publishing peer reviewed articles based on SICB symposia ICB has become a go to resource for foundational and forward looking work in organismal biology. The brand new IOB is published as an open access journal, and has introduced double-blind peer review, a mindful editorial process focused on constructive guidance, and multilingual abstracts. Both ICB and IOB have built inclusive editorial boards and promote authors and their science through social media. In 2019, both IOB and ICB achieved high scores in both traditional, citation-based metrics as well as complementary social-media based metric: IOB was ranked first among biology journals for its social media metrics (Altmetrics); ICB achieved its highest impact factor to date (3.101). Both journals successfully cooperate to serve the SICB community, and both journals strive to lead through increasing equity and transparency in the scientific publication process. ICB will be on the cutting edge of symposia development by instigating both hybrid symposia and virtual symposia to increase diversity and participation. IOB is soliciting manuscripts on best practices, reviews and commentary adjacent to ICB symposium topics, as well as a diversity of original data manuscripts from all of SICBs divisions. Our journals serve the society in many ways and we count on the membership to think of the journals as places to publish their best work. After the talk we will actively solicit your opinions on new initiatives, such as on equity, accessibility and transparency.

69-2 MUNLEY, KM*; DEYOE, JE; ADANIYA, CH; NOWAKOWSKI, AM; REN, CC; MURPHY, GV; REINHART, JM; DEMAS, GE; Indiana University; *kmunley@indiana.edu*

Melatonin modulates seasonal changes in neurosteroid levels and territorial aggression in male Siberian hamsters (Phodopus sungorus)

Numerous studies have shown that circulating gonadal steroids are positively correlated with aggression during the breeding season. However, it is becoming increasingly clear that alternative neuroendocrine mechanisms are critical in modulating aggressive behavior, particularly for animals that are more aggressive during the short-day photoperiods (SDs) of the non-breeding season. While previous work from our lab suggests that pineal melatonin (MEL) and the adrenal androgen dehydroepiandrosterone (DHEA) are important in facilitating non-breeding aggression in Siberian hamsters, it is unknown whether local changes in steroid synthesis and metabolism within the brain are ultimately responsible for elevating aggression during the non-breeding season. To investigate the role of MEL in mediating seasonal variation in neurosteroid levels and aggression, we housed male hamsters in long days (LD) or SD, treated them with either timed MEL or saline injections, and quantified aggression after 9 weeks of photoperiodic housing. Furthermore, we assessed whether MEL mediates seasonal changes in steroidogenesis by comparing circulating and neural hormone levels in brain regions that are associated with aggressive or reproductive behaviors using liquid chromatography-mass spectrometry. LD hamsters administered MEL (LD-M) exhibited SD-like levels of aggression. Moreover, LD-M and SD animals reduced circulating DHEA and testosterone levels following an aggressive encounter, whereas LD animals elevated circulating androgen levels. Neurosteroid profiles will also be presented and compared across brain regions and seasonal phenotypes. Collectively, this study provides insight into how MEL regulates seasonal changes in aggression, a behavior that is critical for reproductive success.

S10-6 MUNOZ, MM*; ANDERSON, PSL; HU, Y; PATEK, SN; CAMARILLO, H; Yale University, University of Illinois, Urbana-Champaign, Brown, Duke University; *martha.munoz@yale.edu*

How Predictable and Correlated are Patterns of Form-Function Evolution?

Mechanical relationships shape how organisms can move, feed, and reproduce, thus impacting all aspects of evolutionary fitness. But, can mechanical relationships be used to predict macroevolutionary patterns of morphological diversity? And, how correlated is form-function evolution among different parts of the body? First, I describe previous work connecting mechanical sensitivity, many-to-one mapping, and rates of morphological evolution in various four-bar linkage systems. Then, zooming in on wrasses (Family: Labridae), I describe whether and how feeding and locomotor traits evolve in a correlated or uncorrelated fashion across the labrid tree. The field of evolutionary biomechanics has a rich conceptual history, but remained relatively data limited (particularly with regards to phylogeny) for decades. Now, more than ever, we are uniquely poised to rigorously and quantitatively link biomechanics, ecology, and phylogenetics in a synthetic framework, and derive clear, directional predictions in form-function evolution.

62-6 MUNTEANU, VD*; DIAMOND, KM; MAYERL, CJ; BLOB, RW; Clemson University, NEOMED; *vmuntea@g.clemson.edu*
Humeral Strains During Climbing in Green Iguanas: Testing Biomechanical Release as a Mechanism Promoting Morphological Transitions in Arboreal Vertebrates
The morphology of vertebrate limb bones is generally expected to reflect differences in the functional demands that they experience. Such different demands often arise through changes in habitat. For example, the limbs of arboreal vertebrates are often longer than those of terrestrial relatives, a feature that may improve reach across gaps between branches, but which would be expected to incur a higher risk of bending and breakage during locomotion on the ground. In addition to resulting from changes in habitat, different demands might also arise between the fore- and hindlimbs, which themselves might be affected differently by changes in habitat. To test this hypothesis, we compared previous measurements of *in vivo* strains from the femur of green iguanas during simulated climbing to new measurements of bone strain from the humerus. Trials were conducted for inclined climbing, and walking on a level, compliant surface, to test whether loads under these conditions were lower than those on stiff, level ground. Such a pattern would suggest that "biomechanical release" from loading demands may have facilitated the evolution of longer limbs. We found that both inclined and compliant conditions increased femoral strains when compared to standard level conditions. However, unlike the hindlimb, there was not a consistent pattern of lower or higher bone strains for the forelimb during trials that simulated arboreal conditions. Synthesizing results from the fore- and hindlimbs, biomechanical release seems to be an unlikely mechanism that promoted limb elongation in arboreal taxa. Instead, limb bone adaptations in arboreal habitats seem to have been driven by selective pressures other than their response to loading.

88-6 MURPHY , C.T*; LYONS, K.M; HADDOCK, W.A; MARTIN, W.N; HELLUM, A.M; BREUER, K.S; FRANCK, J.A; US Navy, University of Wisconsin-Madison, Brown University, Brown University; *christin.murphy@navy.mil*
Feature Variations in Seal Whisker Geometries and the Effect on Vortex Structure
Seals use their highly sensitive whiskers to track the hydrodynamic trails of their swimming prey. These whiskers have a unique undulated surface geometry that affects water flow over the structure and influences vortex shedding. Whisker geometry varies between species but the effect of these morphology variations is unknown. By creating whisker models with dramatically modified features, we are able to isolate the effects of specific geometric parameters. Models were tested both computationally and experimentally. For computational fluid dynamics (CDF) simulations, sixteen digital models were generated that isolated seven non-dimensional parameters including undulation wavelength, thickness, slenderness, amplitudes in the streamwise and transverse flow directions, as well as a peak-shift and a symmetry parameter that induce a non-sinusoidal periodic undulation. CFD simulations produced a ranked list of important features that are most influential for reducing drag, root-mean-square lift force, and shifting the frequency spectra. Of these, wavelength was revealed as an important feature. Four physical models (with wavelength as the only variant) were 3D printed and tested in a water tunnel using dye visualization, at the biologically relevant Reynolds number range of 250-800. Flow visualization demonstrated the ability of the undulations to enhance the spanwise momentum transport, reduce the recirculation region, and modify the frequency spectra in the recirculation region behind the whisker.

60-2 MURRAY-COOPER, M*; OZKAN-AYDIN, Y; AYDIN, E; NACLERIO, N; MCCASKEY, E N; HAWKES, E; GOLDMAN, D I; School of Physics, Georgia Tech, Mechanical Engineering, UC Santa Barbara; *mmurraycooper@gatech.edu*
Robophysical Investigation of Root Nutation through Heterogeneous Environments
Circumnutation, a cyclic endogenous circular pattern exhibited by the tip of a growing root, occurs in a diversity of plants, but its function is not fully understood. A previous study observed that rice roots with circumnutating root tips had a higher probability of finding holes that were uniformly distributed on a horizontal plate than mutant roots that grew without circumnutating (Lehner et al. BioArxiv CITE). To investigate the hypotheses that nutation facilitates substrate penetration and exploration, we built a planar soft robot [Hawkes et al. 2017], which grows from the tip like a plant root and can bend in 2D space by oscillating inflation of the series pneumatic artificial muscles (sPAMs) arranged on the two sides. We studied how tip oscillation affected penetration in a heterogeneous environment, a lattice of rough cylinders (d=8cm) distributed uniformly in a bounded free space (120X120cm^2). Systematic variation of initial robot starting positions horizontally across the lattice revealed that the non-oscillating tip strategy led to a high probability of becoming pinned to obstacles; the robot was unable to grow more than an average depth of 23.8±19.7cm . The oscillating tip penetrated the lattice significantly further on average, 55.2±24.9cm , typically via discovery of "corridors" in the lattice. Even in randomized lattices, the nutation facilitated sustained growth. The results from the robotic root model suggest that oscillatory movement of a growing structure increases its exploratory capabilities in a heterogeneous environment.

119-2 MUSSER, JM*; SCHIPPERS, K; NICKEL, M; KOHN, A; MOROZ, L; ARENDT, D; European Molecular Biology Laboratory, Heidelberg, DE, University of Florida, St. Augustine, FL; *jmmusser@gmail.com*
Whole-body single-cell RNA sequencing reveals neural elements in a sponge
Sponges are the sister group to nearly all other animals, and lack a nervous system, musculature, and gut. However, genes encoding important neuronal proteins, including key synaptic proteins, have been found in sponge genomes. Using single-cell RNAseq, single-molecule FISH, and Focused Ion Beam SEM (FIB-SEM) we generate a comprehensive molecular and morphological characterization of cell types in *Spongilla lacustris*, a freshwater demosponge. We identify many specialized cell types bearing functional and regulatory signatures similar to those of other animals. This includes contractile epithelial cells, which we demonstrate experimentally are responsive to nitric oxide signaling, phagocytes involved in innate immunity, and digestive cells that express a nearly complete set of postsynaptic genes. Remarkably, we also find immune cells expressing presynaptic genes and show via FIB-SEM that they send long projections that directly contact and enwrap microvilli of 'postsynaptic' digestive cells. This reveals new evidence linking neuronal and immune function in sponges, and suggests a primordial neuro-immune system cleared intruders and controlled ciliary beating for feeding.

21-1 MUTH, F*; FRANCIS, JS; LEONARD, AS; University of Texas at Austin, University of Nevada, Reno; *felicity.muth@austin.utexas.edu*

Bumblebee cognition and the influence of anthropogenic stressors

Bumblebees are an insect model organism for the study of animal cognition, due in part to their aptitude at learning and remembering stimuli while foraging. However, bumblebees are also in decline, in part due to exposure to pesticides that may alter their cognitive abilities. Thus, now is a critical time to fully understand bee cognition involved in their natural foraging behaviour, and how such cognition may be affected by anthropogenic stressors. In this talk, I highlight my recent findings on bumblebee cognition involved in foraging under ecologically realistic scenarios, as well as how neonicotinoid pesticides may be affecting sensory and/or cognitive traits. In particular, I discuss recent findings that neonicotinoid pesticide effects on learning may be modality-specific and what this might mean for bee cognition and foraging more broadly.

63-2 NAISBETT-JONES, L*; TSAI, E; LOHMANN, C; LOHMANN, K; Department of Biology, University of North Carolina, Chapel Hill; *lnaisbettjones@gmail.com*

Navigating the Ocean Floor: Magnetic Compass Orientation of a Marine Flatfish

Gulf Flounder (*Paralichthys albigutta*) hatch at offshore spawning grounds and subsequently migrate to nursery habitats along the coast of the southeastern United States. Yet, the means by which juvenile flounder reach nursery habitats has remained enigmatic. Recent studies have demonstrated that migratory fishes such as eels and salmon navigate using Earth's magnetic field. However, whether flounder – or any flatfish – possess a geomagnetic sense has not previously been investigated. We used a magnetic coil system to test whether flounder use Earth's magnetic field for directional or "compass" orientation. Fish tested in a water-filled arena in the unaltered ambient magnetic field oriented toward magnetic west, a direction consistent with their onshore migration. When the coil was used to reverse the direction of the horizontal field, the fish showed a corresponding shift in orientation. These findings demonstrate that Gulf Flounder have a magnetic compass that can be used in orientation, and which may guide young fish as they migrate from the open sea to coastal nursery habitats. These results provide new insight into the migration ecology of flounder and suggest that a magnetic compass may facilitate the diverse migrations of marine flatfish.

24-8 NAMES, G*; KRAUSE, J; SCHULTZ, E; HUNT, K; HEAL, M; HAHN, T; CORNELIUS, J; WINGFIELD, J; Univ. of California, Davis, Univ. of Nevada, Reno, Wittenberg Univ., George Mason Univ., Bangor Univ., Oregon State Univ.; *grnames@ucdavis.edu*

Immunological consequences of circulating corticosterone: an experimental investigation comparing avian malaria-tolerant and -susceptible Hawaii Amakihi (Hemignathus virens)

Infectious diseases are spreading at unprecedented rates, reducing the abundance, distribution, and/or long-term viability of many wild animals. Avian malaria has recently contributed to the decline of several endemic Hawaiian birds. Fortunately, some populations of the native Hawaii Amakihi (*Hemignathus virens*) display tolerance to the disease. We sought to experimentally determine the effect of corticosterone (CORT), an immunosuppressor, on immune function and malaria infection in wild Amakihi. Based on our field data, which show reduced CORT increase in response to capture and restraint stress in tolerant versus susceptible populations, we hypothesized that variation in circulating CORT influences malaria tolerance. To test this, we studied 40 captive adult males from tolerant and susceptible populations, implanting each with a CORT (n = 20) or sham (n = 20) silastic implant for 4 days and measuring immune function and malaria infection on day 0 (before implant), 2, and 4. CORT levels were higher on day 2 and 4 in CORT than sham birds, with no effect of tolerance status. On day 2, total leukocyte count was elevated in susceptible but not tolerant CORT-implant males compared to sham-implant males, while no differences by tolerance status were detected on day 0 or 4. Hematocrit decreased more during the experimental period in CORT-implant than sham-implant birds with no effect of tolerance status. Our results suggest that immune response may be less influenced by increased CORT in malaria-tolerant than malaria-susceptible birds.

2-3 NARAGON, TH*; BRüCKNER, AK; WIJKER, RS; SESSIONS, AL; PARKER, J; Caltech; *tnaragon@caltech.edu*

Cuticular hydrocarbons and the integration of myrmecophile rove beetles into ant colonies

Cuticular hydrocarbons (CHCs) play a dual role in insects: they prevent against water loss across the cuticle and they are a medium for chemical communication. In eusocial insects the use of CHCs in chemical communication takes on an additional dimension in that the CHCs are used not only for recognition of conspecifics but also for the recognition of members of the same colony. While the complex CHC signature allows ants to identify the majority of nest intruders, a large number of arthropods have nonetheless evolved to live inside of ant colonies via a number of different mechanisms. Of these so called myrmecophiles or ant lovers, the most intimately integrated species often mimic the CHC profile of the host colony, thus reducing, and in some cases entirely avoiding, detection within the colony. Within the colonies of the ant *Liometopum occidentale* two species of myrmecophile rove beetles have evolved to mimic the CHC profile of their host ant. Using a combination of GCMS and stable isotope mass spectrometry we analyzed the CHCs in the two beetle species to identify the mechanism by which the beetles obtained the compounds. In agreement with behavioural observations, we found that the beetle *Sceptobius lativentris* steals its CHCs from *L. occidentale* via a specialized grooming behavior whereas the beetle *Platyusa sonomae* synthesizes a large fraction of its own CHCs. These beetles embody two radically different approaches to chemical mimicry, either via modification of CHC synthesis machinery or through the modification of behavior, and represent a useful system for studying convergence in symbiotic systems.

7-6 NASH, S/B*; RAHMAN, S/M; University of Texas Rio Grande Valley, Brownsville, TX; *sarah.b.nash96@gmail.com*
Short-term heat stress attenuates gonadal functions and induces apoptosis and oxidative stress in the American oyster, Crassostrea virginica: molecular mechanisms and signaling pathways
Global climate change is predicted to intensify thermal stress in marine and coastal organisms, affecting their development, growth, and reproductive functions. In this study, we examined the effects of short-term exposure to elevated temperatures (28 and 32°C for 1-week) on gonadal functions, heat shock protein-70 (HSP70), dinitrophenyl protein (DNP, a biomarker of reactive oxygen species, ROS) and nitrotyrosine protein (NTP, an indicator of reactive nitrogen species, RNS) expressions, protein carbonyl (PC, a measure of ROS) contents, nitrates/nitrites (NOx, a metabolite of nitic oxide), extrapallial fluid (EPF, an important body fluid) conditions, and cellular apoptosis in American oyster (*Crassostrea virginica*, an important marine species). Oysters exposed to higher temperatures significantly decreased the number and diameter of eggs and sperm production, and EPF protein concentrations compared with controls (24°C). In contrast, EPF pH, gonadal HSP70 protein expression were increased after heat exposure, consistent with increased gonadal apoptosis. The enhanced apoptosis in gonads were associated with increased gonadal caspase-3/7activity, PC contents, NOx levels, and NTP and DNP expressions in heat-exposed oysters. Collectively, these results suggest that higher temperatures drastically increase RNS and ROS levels, increasing incidence of apoptosis and subsequently reducing gonadal functions in oysters. To the best of our knowledge, this study reports the first findings on the impacts of elevated temperatures on gonadal functions in oysters.

95-8 NAVARA, KJ*; WROBEL, ER; BENTZ, AB; LORENZ, WW; GARDNER, S; MENDONçA, MT; The University of Georgia, Indiana University, Bloomington, Auburn University; *knavara@gmail.com*
Corticosterone treatment influences expression of gene pathways linked to meiotic segregation in preovulatory follicles of the domestic hen
Decades of work indicate that female birds can control their offspring sex ratios in response to surrounding cues. In laying hens, hormones administered immediately prior to sex chromosome segregation can exert sex ratio skews, indicating that these hormones may act directly on the germinal disc to influence which sex chromosome is retained in the oocyte and which is discarded into an unfertilizable polar body. We aimed to uncover the gene pathways involved in this process by testing whether treatments with testosterone or corticosterone that are known influence sex ratios elicit changes in the expression of genes and/or gene pathways involved in the process of meiotic segregation. We injected laying hens with testosterone, corticosterone, or control oil 5h prior to ovulation and collected germinal discs from the F1 preovulatory follicle in each hen 1.5h after injection. We used RNA-sequencing followed by DESeq2 and gene set enrichment analyses to identify genes and gene pathways that were differentially expressed between germinal discs of control and hormone-treated hens. Corticosterone treatment triggered downregulation of 13 individual genes, enrichment of gene sets related to meiotic spindle organization and chromosome segregation, and additional gene sets that function in ion transport. Testosterone triggered upregulation of one gene, and enrichment of one gene set that functions in nuclear chromosome segregation. This indicates that corticosterone can be a potent regulator of meiotic processes and provides potential gene targets on which corticosterone and/or testosterone may act to influence offspring sex ratios in birds.

9-6 NAVE, GK*; TALLACKSON, H; PELEG, O; University of Colorado, Boulder; *Gary.Nave@colorado.edu*
The Formation of Honey Bee Swarms
When a European honey bee (*Apis mellifera*) colony outgrows its nest, the colony divides in two, sending a queen and about half the workers in search of a new home. To survive this transition, the outbound group will find a tree branch or other surface and hang together in a swarm while scouts search and decide on a permanent nest location. While this decision-making process of swarms has been well studied, the mechanical aspects of the formation of the swarm on its anchoring surface have not previously been studied. In this work, we will present both experimental and computational work on the formation of honey bee swarms to address the question: How do honey bees decide where to attach to a growing honey bee swarm? To gain insight into this question, we conduct experimental observations of swarm formation and replicate the observed behavior through computational modeling. With the queen confined to a cage, we induce the bees into a swarm under a horizontal surface and allow the bees to locate a new nest site and leave. Because the queen does not travel with them, we record the re-formation of the swarm as the bees return to her. Then, we use agent-based modeling techniques to model swarm formation as an aggregation problem, modeling the decision-making process of where bees join the swarm as it grows. With these modeling techniques, we are able to test various rules for swarm formation and assess their accuracy in reproducing our experimental results. A better understanding of the mechanics and behavior of honey bee swarms will allow for better design of, for example, self-assembling multi-agent robotic systems.

73-2 NAVON, D*; ROGERS, SM; HIGHAM, TE; University of California Riverside, University of Calgary; *dina.navon.3@gmail.com*
Behavioral Variation in Feeding Strikes across Five Populations of Threespine Stickleback (Gasterosteus aculeatus)
Investigating the mechanisms by which natural populations diverge to exploit new ecological resources remains of critical interest to evolutionary biologists. Evolutionary changes in behavior may be integral in initiating adaptive shifts, yet little is known about the microevolutionary changes in behavior that follow the invasion of new habitats. Threespine stickleback offer a unique opportunity to study microevolutionary variation in behavior and biomechanics due to their rapid, repeated invasion of freshwater habitats from a marine ancestor. Here we examine trophic and locomotor kinematics across five populations of threespine stickleback (4 freshwater and 1 marine). We further characterize their responses to both evasive and non-evasive prey, asking whether these populations exhibit significant behavioral plasticity in response to different prey types. We additionally ask whether these kinematics are integrated, and whether patterns of integration are similar among populations. Finally, we examine these traits in lab-raised fish from each population. We ask how these behaviors develop over time in fish as young as 9 days post fertilization through juvenile stages, and whether development differs among populations. Ultimately, we plan to connect this variation in biomechanics and integration to the underlying genetic architecture by performing a series of genetic mapping crosses between our marine and freshwater populations. This work will add to a growing body of literature investigating the genetic basis of behavioral variation, and will serve as a first step to understanding how biomechanical variation and plasticity evolve in a well-known adaptive radiation.

78-7 NAYLOR, ER*; HIGHAM, TE; University of California, Riverside; *emily.naylor@email.ucr.edu*

Toes for any occasion: morphological covariation and ecological signal within the gecko attachment system

Within geckos, elaborately integrated toe pads holding highly branched setae confer dynamic attachment on a variety of substrates. While frictional adhesion is considered key to diversification, penetrating and interlocking claws are ancestral and nearly ubiquitous features within lizards. Geckos exhibit multiple attachment character states through claw and pad loss that may reflect different selective regimes, such as a mixed substrate environment favoring the presence of both features. Recent experiments have only scratched the surface of the pad-claw functional interplay but do show texture-dependence (e.g., claws dominant on rough substrate). That geckos also display multiple pad types and degrees of claw reduction calls for a more holistic approach to understand their association and evolutionary significance. How do these features covary, and does phylogeny and/or habitat use drive these patterns? We dissected and imaged the fourth pedal digit of specimens within Gekkonoidea, from which we scored and measured aspects of the pad and claw. After size and phylogenetic correction, we saw little correlation between trait measurements, but PGLS models indicated that pad type predicted some variables, such as more strongly curved claws in leaf-padded species. PhyANOVAs revealed smaller pads in generalist and terrestrial species relative to scansorialists and longer setae in saxicolous geckos. Smaller pads have been noted in more terrestrial anoles and thus may reflect reduced functional demands, but the relationship between setal length and actual performance has yet to be resolved in padded lizards. This project provides important evolutionary and ecological insights into gecko autopodial diversity and perspective for the evolution of complex functional systems.

45-2 NEFF, BD; Western University, London, ON; *bryandneff@gmail.com*

Hormones and Behavior in Sunfish: Celebrating 17 years of Collaboration with Rosemary Knapp

A longstanding focus of my research has been to bridge levels of analysis from mechanism to adaptation. One of the first avenues in this pursuit was to understand the role of androgens in mating and parental care behavior in bluegill sunfish. This interest began when I met Rosemary Knapp in 2002, at the EEEF conference, and our collaboration began. Some of our first work together revealed that circulating androgen levels in parental male bluegill show a consistent pattern during breeding bouts: starting highest when males were mating with females, declining while the males were providing parental care, and then increasing again as parental care came to an end. To understand this pattern, we first examined the value of high androgen levels during mating, and found that males with high levels sired a greater proportion of the offspring in their nest, thereby increasing their fitness. Next, we experimentally manipulated androgen levels during parental care and showed that high androgen levels reduced males' nurturing behavior toward the offspring, providing a potential adaptive explanation for the drop in androgen levels during parental care. Our work, which was sadly cut short, was beginning to examine the interplay between androgens and prolactin, as well as identifying specific genes that underlie parental and mating behavior and their fitness consequences.

77-3 NEGRETE JR, B*; ACKERLY, KL; ESBAUGH, AJ; The University of Texas at Austin Marine Science Institute; *bnegrete@utexas.edu*

The effect of hypoxia induced hemoglobin switching on aerobic performance in red drum, Sciaenops ocellatus

The Gulf of Mexico experiences one of the largest seasonal hypoxic zones in the world, exposing endemic fish to chronically O_2-limited waters. Previous work on red drum – a resident of the coastal waters of the Gulf of Mexico – has demonstrated they can dynamically regulate specific hemoglobin subunits in response to chronic hypoxia exposure, which result in lower blood oxygen binding affinity and a reduced whole animal critical oxygen threshold. Here, we will build upon this prior work by exploring the time course of red blood cell plasticity, and assess the impacts on maximum metabolic rate. Fish were acclimated to 30% air saturation for 1, 4, 8, 14, or 42 days, and red blood cells were collected for gene expression and biochemical profiling. Relative hemoglobin isoform abundance was assessed using real-time PCR and thin-layer isoelectric focusing. Additionally, hematocrit (red blood cell concentration) and NTP concentration were measured. Hb patterns showed up-regulation in Hb 2 by 50-fold relative to control in response to hypoxia starting at 4 days. Hematocrit showed a difference in treatment at 8-days, with no change over other time points between treatments. Red drum do not show changes in [NTP] in hypoxia, suggesting they regulate Hb-O_2affinity through other changes in the red blood cell such as hematocrit and Hb. Thus, the effects of the observed red blood cell plasticity on whole animal performance were tested by assessing maximum metabolic rate of hypoxia and normoxia acclimated individuals at 50% oxygen saturation for at least 8-days.

133-6 NEUROHR, JM*; KINSEY, ST; University of North Carolina Wilmington; *jmn6284@uncw.edu*

The Impact of Tissue Aerobic Capacity and Life Stage on Oxidative Damage and Protein Turnover in Skeletal Muscle of the Blue Crab, Callinectes sapidus

Reactive oxygen species (ROS) are produced largely by mitochondria in skeletal muscle as a natural by-product of aerobic metabolism and have the potential to elicit oxidative stress. The blue crab, *Callinectes sapidus*, is a high-performance swimming crab, with an ability to undergo anaerobic burst swimming during predator-prey interactions, as well as aerobic endurance swimming during extended daily or seasonal migrations. The locomotor muscles that power these two types of swimming represent extreme ends of the aerobic spectrum. The aerobic (dark) muscles that power endurance swimming have a mitochondrial volume density (MVD) that is *25 times higher* than the anaerobic (light) fibers that power burst swimming. We tested the hypothesis in juvenile and adult crabs that the much higher MVD in dark muscle leads to oxidative damage that may necessitate greater rates of turnover of intracellular components. Juveniles had greater protein carbonylation in both dark and light muscle, and greater lipid peroxidation in dark muscle than in adults. There was no difference in oxidative stress markers between muscle types. Surprisingly, relative protein translation rates were not different between muscle types, and dark muscle in juveniles had a lower translation rate than in adults. Ubiquitin was greater in light muscle of juveniles than in adults while calpain was not different between life stages. Calpain was significantly greater in light relative to dark muscle in adults. These results indicate that the extreme difference in MVD between muscle types does not lead to a proportional difference in oxidative stress or protein turnover, suggesting mechanisms exist to limit net ROS production in dark muscle.

124-6 NEWBREY, JL*; LOVE, Q; NEWBREY, MG; Department of Biology, Columbus State University, Columbus, GA; *newbrey_jennifer@columbusstate.edu*

Differences in Yolk Carotenoid Concentrations of Three Songbird Species Breeding in Nest Boxes in Georgia, USA

We identified and compared yolk carotenoids from the eggs of three species of secondary-cavity-nesting songbirds in west-central Georgia, the Tufted Titmouse (*Baeolophus bicolor*), Brown-headed Nuthatch (*Sitta pusilla*), and Carolina Wren (*Thryothorus ludovicianus*). Carotenoids are biologically-active pigments that act as powerful antioxidants and immunostimulants for both developing embryos and adult birds. Female birds allocate high concentrations of carotenoids to their egg yolks, where the pigments protect developing embryos against damage to lipids, proteins, and DNA. Despite this critical role that yolk carotenoids play in avian reproduction, surprisingly little research has focused on North American songbirds. Therefore, the third-laid egg was collected from 16 nuthatch nests, 7 titmouse nests, and 23 wren nests, for a total of 46 eggs. Yolk carotenoids were extracted and quantified using high performance liquid chromatography. We identified three dietary carotenoids in the eggs of the study species, -carotene, lutein, and zeaxanthin. Yolk concentrations of -carotene did not vary across the species, but wrens had the highest concentrations of lutein and total carotenoids, and nuthatches had the lowest concentrations of zeaxanthin. The differences we found in yolk carotenoid concentrations in the three study species are likely linked to differences in diet. Brown-headed Nuthatches consume more seeds than the other two species during egg formation, whereas Tufted Titmice and Carolina Wrens consume more invertebrates. However, further research on dietary sources of carotenoids for these three species is needed to better understand the yolk carotenoid concentration differences we observed.

17-7 NEWCOMB, JM*; GINGRAS, MA; NELSON, SN; MCGHEE, CB; EASTER, JH; GOODHEART, JA; RAMIREZ, MD; New England College, University of California, Santa Barbara, University of Massachusetts, Amherst; *jnewcomb@nec.edu*

Nudibranch opsins: identification, localization and potential roles in extraocular photoreception and circadian rhythms

R-type (rhabdomeric) opsins are common light-sensitive proteins in invertebrate eyes. R-opsins have been identified in the eyes, brain and skin of numerous molluscs, but not in nudibranchs, which was the goal of this study. We focused on *Berghia stephanieae*, *Hermissenda opalescens* and *Melibe leonina*, the latter two of which have publicly available transcriptomes. From these, we identified multiple types of opsins in both species. Using these sequences, we developed RNA probes for fluorescent *in situ* hybridization (FISH) and found r-opsin mRNA expression in all dermal tissues that we examined. Immunohistochemistry with antibodies to octopus r-opsin corroborated the FISH results and also indicated a similar localization in dermal tissues of *Berghia*. In behavioral experiments to test for extraocular photoreception, *Berghia* and *Melibe* both responded to extraocular stimulation using both white and red light, but not infrared wavelengths. R-opsins were not detected in the brains of *Berghia* and *Hermissenda*, but were expressed in a small number of neurons in the brain of *Melibe* in a similar location to previously identified circadian clock neurons. Double-label FISH experiments confirmed the colocalization of r-opsin with core clock transcripts in the brain. Additional experiments extended this colocalization to dermal tissues. Together, these data suggest that r-opsins are prevalent in dermal tissues of nudibranchs and may play a role in both extraocular photoreception and direct input to central and peripheral circadian clocks.

124-2 NGUYEN, H; HOANG, T; HAWKINS, D; DRECHSLER, J; NILSSON, P; STEINER, B; PERNET, B*; California State University Long Beach; *bruno.pernet@csulb.edu*

Are larvae of the sand dollar Dendraster excentricus food-limited in nearshore waters of southern California?

The feeding larvae of marine invertebrates may often be food-limited in rates of growth and development, a result with important implications for larval ecology and evolution. The generality of this result is uncertain, however, as studies addressing larval food limitation are few, and conflicting results have been reported. We tested for food limitation in larvae of the sand dollar *Dendraster excentricus* in nearshore waters of southern California in six experiments from 2017-19. In each experiment we compared the form and development rates of larvae reared in natural seawater (NS) to those of larvae reared in natural seawater supplemented with *Rhodomonas lens* (NS+); as a control, we also reared larvae in natural seawater diluted 1:1 with filtered seawater (NS-). During our experiments, chlorophyll a levels in NS treatments were fairly high, ranging from 1.48-4.57 μg L^{-1}. Despite this, compared to NS+ larvae, larvae reared in NS consistently had slightly higher postoral arm/midline body length ratios, indicative of a phenotypically plastic response to low food levels, and slightly greater time to 50% metamorphic competence, suggesting subtle food limitation. Larvae reared in NS- were very clearly food-limited: they always had much higher postoral arm/midline body length ratios and much greater time to 50% competence than did larvae in the other two treatments. Our results suggest that even in habitats with relatively high standing stocks of chlorophyll a, larvae may routinely experience food limitation.

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Construction and Deconstruction of Muscle Work Loops

Muscles are actuators that exert forces to influence animal movement, but are also active, soft materials that exert forces in response to external perturbations. Rheology, the study of deformation of matter, uses sinusoidal perturbations as an important tool in the study of soft matter, and muscle work loops are a generalization of that tool. Although work loops are often quantified in terms of net work performed by the muscle, the complete shape of a work loop is an important part of a muscle's effects on animal movement. Muscle rheology varies with both the neural excitation and the external perturbation it receives; the rheology of interest is thus the entire set of possible loop shapes assumed by a muscle across its physiologically relevant excitation patterns and perturbations. We address here the question of classifying loop shapes so as to compare loops measured across different experimental conditions. We present a work loop construction for muscles with a time-varying excitation using ellipses formed from loss/storage moduli as an illustrative example. Each ellipse corresponds to a constant excitation level, and the construction splices together multiple ellipses to form the muscle's work loop for a time-varying excitation. This motivates a deconstruction of measured loops, if the excitation pattern is known, into ratios of work contributions by elastic, viscous, and ideal forces. All possible loop shapes for muscles undergoing small sinusoidal perturbations are categorized by these ratios. The details differ for other perturbations or if the muscle's rheology is nonlinear, but the viewpoint of muscle work loops obtained under time-varying excitation as spliced basis loops obtained under constant excitation adds a systematic interpretation of loop shapes and muscle rheology.

43-8 NICHOLSON, DJ*; LOGAN, ML; COX, CL; MCMILLAN, WO; GARNER, TWJ; KNELL, RJ; Queen Mary University London, University of Nevada, Reno, Florida International University, Smithsonian Tropical Research Institution, Zoological Society of London; *danielnicholson49@gmail.com*

Population dynamics and morphological change after experimental colonization of a novel environment.

Anthropogenic actions are rapidly redistributing species and allowing novel colonization events. With this colonization comes exposure to new habitats and environments. Rapid changes in the environment can cause a populations mean phenotype to become mismatched with local fitness optima or limit a population's adaptive potential. This mismatch in phenotype can drive directional selection, and while this may lead to higher mean population fitness it also leads to high mortality, affecting population dynamics. Using an experimental island system, we investigated the initial stages of colonization and some of the underlying adaptive mechanisms linked with persistence in a novel environment over three generations in the Panamanian anole (*Anolis apletophallus*). We transplanted hundreds of uniquely-marked adult lizards from a single source population on mainland Panama to four small islands in Lake Gatun (Panama Canal). These islands differ in habitat structure from the mainland. We conducted mark-recapture surveys to assess changes in habitat use, morphology, and population size over three years. After only a single generation, we observed several morphological changes, including a reduction in both head and toe pad size and an increase in limb length across all islands. Several of these changes correspond with changes in habitat use in ways predicted by biomechanical theory. We discuss these results in the context of contemporary evolution and eco-evolutionary dynamics, and what role these factors play in the success of populations that colonize novel environments.

75-6 NOEL, A*; NADLER, J; Georgia Tech Research Institute; *alexis.noel@gtri.gatech.edu*

Mimicking the load-holding capabilities of muscle using electrostatic layer jamming

Biological muscles have the ability to quickly stiffen and hold large loads, two highly coveted traits for soft robotic actuators. Various techniques have been used to replicate the load-holding capability of muscle, from shape memory alloys to pneumatics to cable tension-based systems. When considering wearable technology applications, these techniques often fall short in either responsiveness or load limitations. Layer and granular jamming techniques can allow entirely soft robotic systems to conform and stiffen to environments, much like the soft and highly deformable bodies of various invertebrates. Layer jamming involves many sheaths of a thin material being compressed (commonly by vacuum), increasing the frictional resistance between the sheaths and stiffening the material. Layer jamming was recently used for stiffening a sheath for a snake-like continuum robot, with a focus on surgical robotics. In this experimental study, we investigate, develop, and demonstrate a new mechanism where layered sheaths are quickly stiffened through electrostatic pressure. Using layers of conductive and dielectric material, we vary the friction between the moving surfaces by varying applied voltage, thereby having the ability to quickly control bending stiffness, elongation, and other mechanical properties. The results of this project may provide unique force-feedback solutions for areas such as haptic feedback in virtual reality, or provide realistic muscle stiffening for bio-inspired robotics.

10-5 NIX, RM*; THUESON, K; RABINOWITZ, S; HAVIRD, JC; Baylor University, University of Texas at Austin; *rachel_nix1@baylor.edu*

How do mitochondrial genes with high mutation rates remain functional?

While mitochondrial (mt) genes in bilaterian animals have high mutation rates, mt genomes in most angiosperms evolve slowly. However, in the angiosperm genus *Silene*, some species show mammalian-like ("fast") patterns while closely related species show more typical "slow" rates. This allows us to investigate whether mt function is maintained in "fast" lineages via either: 1) nuclear mutations that compensate for rapidly accumulating, possibly deleterious mt mutations or 2) through strong purifying selection on mt mutations. In this experiment, we compare mt respiration in "fast" species to "slow" species to determine the effect of the many nonsynonymous mt changes that have accumulated in "fast" species. Mt respiration was measured from isolated leaf mitochondria using a new protocol for the Oroboros O2k system. Flux control factors for seven unique respiratory states were calculated to examine the contribution of specific OXPHOS enzymes to respiration (e.g., CI vs. CII). Preliminary results indicate few significant differences in mt function between "fast" and "slow" species. To determine if complementary nuclear changes are responsible for maintaining mt function, respiration was quantified in F2 paternal backcrossed hybrids between two "fast" species, intended to moderately breakup coadapted mitonuclear genotypes. Although germination rates were low in the F2 plants, mt respiration was generally similar to the parental species, with chimeric OXPHOS complexes showing the same or even elevated flux in the hybrids. Together, these results suggest mt purifying selection may be the dominant evolutionary force acting to maintain mt function in "fast" *Silene*. However, nuclear compensation could still play a role. Future research should explore other fast-evolving angiosperm lineages.

10-8 NORDéN, KK*; ELIASON, CM; STODDARD, MC; Princeton University, Princeton, NJ, Field Museum of Natural History, Chicago, IL; *knorden@princeton.edu*

Do diverse feather nanostructures increase the colorfulness of iridescent plumage?

Iridescent bird coloration produces some of the most spectacular color displays in the natural world, yet much of how these colors evolve remains enigmatic. Birds often produce iridescence in their feathers by layering pigment-filled organelles (melanosomes) and keratin in the feather filaments, effectively creating a photonic crystal that reflects only certain colors of light. Typically, melanosomes are solid and cylindrical, but in some iridescent species novel types of melanosomes have evolved, including hollow (air-filled) and flattened morphologies. These derived morphologies have evolved independently multiple times in birds, and likely affect color production. Yet, the interplay between nanostructural diversity and color diversity has never been tested on a large scale. Here, we test the hypothesis that novel melanosome morphologies allow birds to produce a greater diversity of colors. We collected spectral data on 72 iridescent bird species spanning 11 orders and encompassing all types of melanosome morphologies. We combined these empirical data with an optical modelling approach to estimate what colors could theoretically be produced with each morphology, varying a range of optically important parameters. Our results show that birds with derived melanosome morphologies tend to produce brighter and more saturated colors than birds with solid cylindrical melanosomes, which results in a greater possible color diversity. The main evolutionary forces driving the repeated evolution of derived melanosome morphologies might therefore be related to a paired brightness and saturation advantage, compared to the ancestral form.

117-4 NOWICKI, S*; CAVES, EM; SCHWEIKERT, LE; GREEN, PA; TABOADA, C; ZIPPLE, MN; PETERS, S; JOHNSEN, S; Duke University, Durham, NC, University of Exeter, United Kingdom, Florida International University, Miami; *snowicki@duke.edu*

Carotenoid Concentration in Avian Retinal Oil Droplets Correlates with Color Discrimination Across a Perceptual Category Boundary

The ability to discriminate between colors is important across taxa and behavioral contexts. In birds, color discrimination is thought to be enhanced by carotenoid-containing oil droplets found inside photoreceptors. We asked whether variation in the ability of female zebra finches (*Taeniopygia guttata*) to discriminate colors along an orange-red color continuum corresponds to variation in the carotenoid concentration of retinal oil droplets. This color continuum parallels variation in male beak color, a mate assessment signal, and is perceived by both female and male zebra finches in a categorical fashion. We behaviorally tested color discrimination and then used microspectrophotometry to measure cone oil droplet absorbance, a proxy for carotenoid concentration. We found that underlying variation in oil droplet carotenoids corresponds to variation in behaviorally measured color discrimination ability. Oil droplet carotenoid concentration did not affect discrimination ability across the entire orange-red range equally, however. Rather, higher carotenoid concentration was associated only with increased discrimination of colors from different sides of the previously identified color category boundary. These data show that differences in sensory physiology can correlate with individual variation in perception of a signal-relevant color range.

27-2 NUNEZ, SA*; SANGER, TJ; Loyola University Chicago; *snunez3@luc.edu*

The Physiological Basis of Structural Malformations in Thermally Stressed Lizard Embryos

Global warming is driving species beyond their thermal physiological limit. Oviparous species, such as reptiles, may be negatively impacted by climate change as their eggs will be laid and incubated at progressively higher temperatures. *Anolis* lizards subjected to thermal stress during early embryonic development experience decreased survival and increased rates of craniofacial malformation, yet the mechanisms driving these patterns remain unknown. It has been suggested that oxygen restriction sets the thermal range of embryonic development (i.e., oxygen limitation hypothesis). We hypothesized that hypoxic conditions would lower the thermal threshold of *Anolis* embryos while hyperoxic conditions would buffer the effects of thermal stress. We discovered that embryos developing under hypoxia at sublethal temperatures produced craniofacial malformations similar to thermally stressed anole embryos. In contrast, embryos developing under hyperoxic conditions and typically lethal temperatures developed normally. To clarify the potential role of oxidative stress, we measured the activity of the antioxidant enzyme superoxide dismutase (SOD) in anole embryos incubated at varying temperatures. Initial trials show that increased temperature leads to increased SOD activity in the developing head and brain. Additionally, preliminary results indicate a hypoxia marker, Hypoxia inducible factor 1-alpha, is present in the developing brain of thermally stressed anole embryos. Our results suggest that oxygen limitation and oxidative stress may explain how structural malformations arise during embryonic thermal stress, and why survival is negatively impacted at high temperatures. We elucidate a potential mechanism of induced craniofacial defects in thermally stressed lizard embryos.

140-8 O'CONNELL, J; SHAMBLE, P; KOENIG, K*; Standford University, Harvard University; *kmkoenig@fas.harvard.edu*

Comparative Lens Proteomics Across Aves

The proteins in the lens that contribute to transparency and light refraction are crystallins. These proteins have an interesting and complicated evolutionary history with surprising diversity across closely related taxa. Many of these proteins have secondary functions as metabolic enzymes and heat shock proteins. Even more unusual, crystallins , and are common in vertebrates but individual taxon-specific crystallins have been identified as well. One of the most remarkable examples is the high abundance of lactate dehydrogenase B in the duck lens, designated -crystallin, is lacking in the chicken lens. Since this discovery in 1985, progress towards a phylogenetic understanding of lens protein content and evolution has been slow due to the difficulty of performing large-scale protein analysis across species. Recent advances in proteomic methods and the availability of whole-genome sequences now enable our ability to perform broad, cross-species protein content analysis to better understand crystallin protein diversity and lens evolution. Lenses from a phylogenetically diverse sample of bird species were acquired for proteomic analysis. The tissue was analyzed for protein identity and relative abundance using both in-solution and gel-band extraction sample preparations followed by shotgun mass spectrometry. Protein abundances were quantified by normalized spectral counts and integrated ion intensities. Genomic regions surrounding genes identified in the lens proteomics studies were found in the corresponding bird species and comparative sequence analysis was performed. We see significant lens protein content diversity across species as well as differences in relative abundances. These results provide a better phylogenetic understanding of the diversity and unusual regulatory history of crystallin proteins in the bird lens.

S5-4 O'DONNELL, MK*; DEBAN, SM; Brown University, University of South Florida; *mary_kate_odonnell@brown.edu*

The Effect of Water on Salamander Cling Performance at the Critical Roughness

Plethodontid salamanders are capable of extraordinary clinging and climbing performance. This has enabled them to access arboreal, saxicolous, troglodytic, terrestrial, and fossorial habitats to find shelter, access food, and escape predators while traversing substrates in nature that can be rough or smooth, wet or dry. Since these lungless salamanders are dependent on moist environments to ensure sufficient cutaneous respiration, the effect of water on clinging and climbing performance may constrain which habitats they have access to. We previously found that salamanders are capable of high cling performance on both smooth and roughened dry epoxy resin surfaces, depending on their body size, foot morphology, and attachment strategy. Cling performance was weakest on surfaces at a critical intermediate roughness. Salamanders cling to smooth and intermediately roughened surfaces purely through the adhesive strength of their mucus coating. Here, we examined the effect of misted and flowing water on cling performance across a range of substrate roughnesses in 12 species of plethodontid and one ambystomatid salamander. We found that water negatively impacts cling performance on smooth surfaces, but significantly improves cling performance at the critical roughness in some species. On rough substrates where salamanders could engage in gripping, water had no significant effect on cling performance. Study of cling performance and its relationship to surface roughness and wetness may cast light on how the largest family of salamanders in the world have radiated to occupy diverse habitats and inspire synthetic adhesives which function in both dry and wet conditions.

30-2 O'MARA, MT; AMORIM, F; SCACCO, M; MCCRACKEN, GF; SAFI, K; MATA, V; TOMÉ, R; SWARTZ, SM*; WIKELSKI, M; BEJA, P; REBELO, H; DECHMANN, DKN; Southeastern Louisiana University, Hammond LA, University of Porto, Portugal, Max Planck Institute of Animal Behavior, Radolfzell, Germany and University of Konstanz, University of Tennessee, Knoxville TN, Max Planck Institute of Animal Behavior, Radolfzell, Germany and University of Konstanz, University of Lisbon, Portugal, Brown University, Providence, RI , University of Porto and University of Lisbon, Portugal; *teague.omara@selu.edu*

European Free-tailed Bats Use Wind Regimes to Fly High and Fast

Bats use some of the fastest known vertebrate flight speeds and can forage thousands of meters above the ground, but it is unknown how they manage these high-energy behaviors. We tracked the three-dimensional movement of European free-tailed bats (*Tadarida teniotis*) in northeastern Portugal and developed high resolution wind models to test if bats use the underlying landscape and wind regime to generate high speeds and achieve high flight altitudes. Bats flew at speeds of 5.63 ± 3.66 m/s (maximum 41.24 m/s or 149 km/h) with airspeeds of 4.68 ± 3.79 m/s, (maximum of 37.52 m/s, 135 km/h). Bats largely follow the terrain at 182 ± 206 m above ground level (AGL), but appear to ride uplifting winds to travel hundreds of meters upwards in less than one minute to over 1600 m AGL. Predictive additive models using wind patterns alone are able to predict the location of these high-elevation ascents and explain 91.3% ± 11.1% of the deviance. This suggests that bats exploit the energy in vertical winds generated by the interaction between wind and topographic slope to minimize energetic expenditure, similar to diurnal birds, and likely follow a path of least resistance to high-elevation hunting grounds. Free-tailed bats generate some of the fastest powered flight speeds among vertebrates, forage at exceptional altitudes, and continue to challenge our understanding of flight in the wild.

119-7 OAKLEY, TH*; HENSLEY, NM; ELLIS, EA; GOODHEART, JA; VARNEY, RM; GERRISH, GA; TORRES, E; UCSB, U Alabama, UW-Madison, CSULA; *oakley@lifesci.ucsb.edu*

From Chaos Came Beauty: The Origin of a Novel Bioluminescence Gene with Ecosystem Impacts

Bioluminescence is ecologically impactful through its use in communication, including courtship signals whose origins may increase rates of speciation. Therefore, learning how genes for bioluminescence originate is critical for understanding how genetic changes influence ecological communities. One origin of bioluminescence occurred in cypridinid ostracods (Crustacea), some of which employ complex bioluminescent courtship displays that differ among dozens of species. Cypridinid bioluminescence involves a novel enzyme (c-luciferase) with two deeply conserved sequences, both Von Willebrand Factor D (VWD) domains. We characterized the history of VWD to inform the origin of this novel gene. We analyzed VWDs in animal genomes, finding them as parts of many different genes with distinct domain architectures. We next included VWDs from ostracod transcriptomes and a draft genome, and discovered c-luciferase originated through novel fusion of distantly related VWD domains. Unexpectedly, we found VWDs proliferated in ostracods before the origin of bioluminescence. Many of these genes contain highly repetitive elements, suggesting a chaotic evolutionary history. Although we still have much to learn about the function of genes related to c-luciferase, this mode of gene origin may be similar to Innovation Amplification Duplication (IAD), but with different timing. Our results illustrate how contingent, unpredictable genomic histories contribute to new genes and ecologically impactful, sometimes beautiful, phenotypes.

46-4 OEL, AP*; LAMANNA, F; HERVAS-SOTOMAYOR, F; KAESSMANN, H; ARENDT, D; EMBL Heidelberg, Germany, ZMBH, University of Heidelberg, Germany; *phillip.oel@embl.de*

Evolution of retinal cell types in the sea lamprey, Petromyzon marinus

The advent of single cell RNAseq has enabled the transcriptomic comparison of cell types within and between species. By characterizing the cell type diversity of phylogenetically diverse animals, we can identify how and when key innovations in cell types have occurred in various lineages. Here, we present progress in documenting the diversity of photoreceptor cell types in the sea lamprey *Petromyzon marinus*, a basal branching jawless vertebrate. We dissociated retinas and brains of larval and adult lamprey, generating ~15,000 retinal cell transcriptomes for each stage with Chromium 10X technology, clustered them with Seurat in R, and validated markers for key cell type clusters with *in situ* staining methods. The adult lamprey retina showed overt cell type conservation with jawed vertebrates, although canonical markers of retinal ganglion cells and amacrine cells labeled both populations variably, suggesting that these cell types are not yet fully distinct in jawless fishes. Additionally, the photoreceptors and bipolar cells expressed deep brain opsins highly, suggestive of nonvisual photoreceptive roles. In stark contrast, the histologically simple retinas of the larval lamprey lacked most markers for bipolar cells, suggesting that larvae lack this cell type. Additionally, the larval photoreceptors were devoid of visual opsins, expressing only deep brain opsins, suggesting that larval retinal photoreceptors first differentiate as ambient light sensors resembling pineal and deep brain photoreceptors. Together, our data support the photoreceptor origin of bipolar cells, and the evolution of retinal, pineal, and deep brain photoreceptors by division of labor.

19-2 OHDERA, AH*; SHARP, V; WATSON, K; STEINWORTH, B; DIAZ-ALMEYDA, E; POOLE, AZ; FITT, W; MARTINDALE, MQ; MEDINA, M; Pennsylvania State University, University of Florida, New College of Florida, Berry College, University of Georgia; *aohdera@caltech.edu*

Alterations in transcriptional and developmental regulation: Evolutionary implication of symbiosis in Cassiopea xamachana

While symbiosis can lead to genetic and morphological changes in the both the host and symbiont, few examples exist in which host developmental transition becomes tightly linked to the symbiosis. Similar to corals, the upside-down jellyfish *Cassiopea xamachana* establishes a symbiotic partnership with members of the dinoflagellate family Symbiodiniaceae. While both host and symbiont benefit from the interaction to fulfill their nutritional requirements, the jellyfish relies on the symbiont in order to complete its lifecycle. In *Cassiopea*, the polyp to medusa transition (strobilation) is triggered by the colonization of the host. In order to understand the mechanisms that lead to strobilation in *Cassiopea*, we used Illumina sequencing to profile the transcriptome of polyps post-colonization and during strobilation. We found genes previously shown to be up-regulated in non-symbiotic jellyfish prior to strobilation were not differentially expressed. A closer examination of these genes showed that while expression levels remain unaltered, in situ hybridization patterns revealed their involvement in *Cassiopea* strobilation is likely maintained. Further assessment of differentially expressed genes of both host and symbiont revealed additional genes that are involved triggering strobilation. These findings shed light on how symbiosis can lead to evolutionary changes in host gene expression and developmental history.

29-1 OLBERDING, JP*; ILTON, M; CROSBY, AJ; AZIZI, E; University of California, Irvine, Harvey Mudd College, University of Massachusetts, Amherst; *olberdij@uci.edu*

Limits and Losses: the Power of Recoiling Biological Springs

Many organisms use springs to actuate extremely fast movements because they can bypass the power limits of other actuators, like muscles. Measurement of muscle-mass-specific power exceeding muscle limits is a common way to identify systems actuated by springs; however, this measurement says nothing about the power of the spring itself. Here we explore the power limits of biological springs and their potential to determine the upper limits of performance in movements actuated by spring recoil. Because a spring applies force to accelerate a mass, we can predict that recoil velocity and power scale as mass$^{-0.5}$ and maximum power is reached when the spring moves only its own mass. However, a spring oscillating at high frequencies releases less energy during recoil than is stored during stretching and this loss is greater at higher frequencies. This leads to the prediction that a spring moving a very light mass will recoil with high velocity, yet much of the stored elastic energy will be lost. Therefore, for any spring there is a specific load mass that balances power output with energy loss. Using a novel experimental approach, we have measured the power of elastic tissues isolated from multiple vertebrate species recoiling with displacements <1 mm and durations <1 ms to move a range of load masses. These measurements confirm the mass-dependent trade-off: recoil power is greater at smaller masses, but energy loss is minimized at larger masses. This result suggests that biological springs must be tuned for the loads they are moving to balance energy and power. Additional experiments will explore the connection between the power/load relationship of a recoiling elastic tissue and material properties, such as resilience and loss modulus.

91-5 OLENSKI, M/S*; BILBREY, C; DIRIENZO, N; DORNHAUS, A; University of Arizona, University of Arizona, School of Information, University of Arizona, Department of Ecology and Evolutionary Biology; *molenski@email.arizona.edu*

The Effect of Neurotransmitters on Life History Strategy: How do Increased Dopamine Levels Influence Aggression in Black Widow Spiders?

Our research is focused on the effects of dopamine on the behavior and individual life history strategies of Black Widow spiders (Latrodectus hesperus). We wanted to perform this experiment to further understand the effects of dopamine in different nervous systems than our own and to better see how the chemical affects individual behavior. The effects of dopamine on the behavior of certain species is well understood, from humans to certain species of insects, but little work has been done on the effects of dopamine on spiders. We compared spiders injected with a solution consisting of .03M dopamine with ones injected with a saline control and a negative control of no injection. Following injections, we then placed spiders on their webs and used a vibratory stimulus on the web to measure individual aggression level. We found that dopamine did not affect individual aggressive behavior, but dopamine injections did decrease the weight of webs. Our results thus suggest that in black widow spiders, individual aggression levels may not be regulated by dopamine; however, our results also suggest that life history strategy, which in spiders is reflected by investment in web building, may be influenced by dopamine.

54-4 OLIVEIRA, DR*; FOSTER, SA; FITZPATRICK, SW; Clark University, Worcester, MA, Michigan State University, East Lansing, MI; *DOliveira@clarku.edu*

Integrating Phenotypes and Genomes in a Fine-Scale Study of Lake-Stream Divergent Rainbow Darters

Populations inhabiting different environments often display phenotypic and genetic differentiation associated with local conditions. Many well-known examples of local adaptation exist from freshwater fish populations occupying varying environments, such as lake versus stream ecotypes. Identifying the adaptive potential of freshwater fish populations is critical, given anthropogenic habitat modification and climate change. However, population-level differentiation has rarely been documented in darters, one of the most species-rich clades of fish in North America. This study assessed fine-scale phenotypic and genetic variation in *Etheostoma caeruleum* (rainbow darters), including a unique lake population. We collected individual data for several phenotypes, including thermal tolerance, morphology, boldness, and locomotion. We characterized neutral and potentially adaptive variation using a modified RADseq protocol. Initial analyses indicate population differentiation for thermal tolerance matching habitat temperature, suggesting local adaptation. We also found a significant pattern wherein populations harbouring more genetic variation have higher thermal tolerance. Furthermore, we found significant lake-stream morphological divergence associated with mouth position, supporting ecotypic differentiation. Despite the small geographic scale, we find evidence of fine-scale genetic structure and recent admixture not owing to stream connectivity. We are currently exploring further ecotype divergent phenotypes and putatively adaptive outlier loci associated with the lake population of rainbow darters.

32-5 OLIVER, KD*; MARTIN, TE; WOLF, BO; University of New Mexico, University of Montana; *kristenoliver@unm.edu*

Air Temperature Limits Metabolic Scope in Mid-elevation Tropical Birds

As global air temperatures continue to rise due to climate change, the effects of temperature on the breeding performance of birds is of increasing interest. If the ability to dissipate heat generated by activities such as foraging and feeding nestlings is diminished in future climates then reproductive success may decrease. With this question in mind, we surveyed a tropical mid-elevation (1500-1900m) bird community in Mount Kinabalu National Park in Borneo, Malaysia where air temperatures range from 15-21ºC. We used a hop-flutter flight wheel and flow-through respirometry to measure resting metabolic rate, exercise metabolic rates, evaporative water loss, and body temperature in 24 species of birds ranging in size from 6g to 140g in dry air over a range of air temperatures (16ºC - 30ºC). Under dry conditions, metabolic scope (peak metabolic rate – resting metabolic rate) and exercise performance were highly diminished at T_{air} > 28ºC suggesting that warmer temperatures may importantly limit activity and potentially breeding performance under future climates.

123-4 OLROYD, SL*; SIDOR, CA; University of Washington, Seattle, University of Washington and Burke Museum, Seattle; *savano@uw.edu*

Allometry and porosity of the novel sound reception structure of chameleons

Chameleons lack a tympanum, but two chameleon species have co-opted their pterygoid plate to serve as a receptor for airborne sound via a connection between this plate and the extracolumella. We hypothesize that the pterygoid plate of these "hearing" chameleons has adaptations that would improve its sound reception function. We expected that the pterygoid plate would exhibit more negative allometry in "hearing" chameleons than in "non-hearing" ones, as negative allometry is common in sensory structures. We also hypothesized that the porosity of the plate would be lower in "hearing" chameleons, reducing the structure's acoustic impedance. We measured basal skull length and pterygoid plate area in chameleon skulls and fitted the measurements to an allometric growth curve. We also μ-CT scanned dry skulls and used CT-An to measure porosity of the plate. We used dissections to identify a connection between the pterygoid plate and extracolumella in four additional species, indicating that this hearing method has evolved at least three times independently. Our preliminary allometry results show that the pterygoid plate has more positive allometry in "hearing" species. This could indicate that chameleons never reach a body size that would allow their plate to be large enough to optimally capture the frequencies they need to hear. Equally surprising was the preliminary result that "hearing" chameleons have a plate with about half the porosity of "non-hearing" ones. This could serve to give the structure a higher resonant frequency in "hearing" species. Overall, our results do suggest that "hearing" chameleons have subtle modifications in their pterygoid plate compared to other species. We intend to explore the acoustic consequences of these modifications through modeling.

97-3 OLSEN, AM*; HERNÁNDEZ, LP; BRAINERD, EL; Brown University, Providence, RI, George Washington University, Washington, DC; *aaron_olsen@brown.edu*

A 13-bar linkage model of the channel catfish skull and the degrees of freedom needed to suction feed

To manipulate their external environment, animals must use the degrees of freedom (DoFs) afforded by their musculoskeletal system to control the DoFs of external objects. For example, grasping a food item with the hand and moving it to the mouth typically requires six DoFs to control the translation and rotation of the food. Suction feeding fishes encounter a similar problem but rather than grasp food items directly, they use a complex linkage of over 10 skeletal elements to manipulate the fluid surrounding the food to capture and transport it to the pharyngeal jaws or esophagus. Do a similar number of degrees of freedom underlie both motor tasks? Previous studies using two-dimensional four-bar linkages suggest fish use just one to three DoFs. However, the skull has over 10 potential DoFs of motion. To answer this question, we created a 13-bar cranial linkage model of the channel catfish first and second jaw arches and validated the model using in vivo data collected using XROMM (X-ray reconstruction of moving morphology). We find that the skull allows at least 14 DoFs of substantial motions (those that affect fluid flow). However, we only observed motion along five of these DoFs. These results show that the manipulation of fluid during suction feeding, though in some ways more complex than grasping a single food item, uses a similar number of DoFs of motion, suggesting analogous strategies in controlling the motion of external objects across terrestrial and fluid domains. Funding: NSF 1612230, 1655756.

85-4 OLSON, RA*; CURTIS, HE; WILLIAMS, SH; Ohio University, Ohio University Heritage College of Osteopathic Medicine; *ro603313@ohio.edu*

To chew or not to chew: a comparison of the 3D kinematics of feeding and drinking in pigs

Feeding has been the primary focus of most 3D kinematic studies of cranial function in mammals. Drinking, on the other hand, has received less interest perhaps due to the emphasis on soft tissue movements responsible for liquid transport through the oral cavity. Nevertheless, the opening and closing of the jaw, or gape cycle, is a fundamental component of both feeding and drinking, and thus can be used as a common basis for comparison between the two behaviors. The objective of this study is to compare the dynamics of the gape cycle, characterized by the durations and amplitudes of 3D jaw movements, and relate jaw movements to tongue movements during drinking and feeding in pigs. We hypothesize that the gape cycles will be similar during both behaviors, but that chewing will exhibit higher levels of variability due to the interactions of the teeth and tongue with food. Data were collected from 3-month old pigs feeding on apples or drinking apple juice. The juice was ingested by a sucking mechanism combined with pumping movements of the tongue. Chewing cycles had an extended slow-close phase, reflecting the tooth-food-tooth contact necessary for preparing a bolus while sucking cycles had an extended slow-open phase, which corresponds to tongue protrusion into the fluid. Compared to chewing, sucking showed low amplitudes for all degrees of freedom used (jaw protraction, yaw, and opening). Sucking cycles were shorter than chewing cycles ($p<0.001$), but had a much higher coefficient of variation (9.47 vs 25.3), suggesting that sucking is not as rhythmic as mammalian chewing. These results provide a context in which to analyze regional tongue movements and deformations relative to the gape cycle.

34-6 ONTANO, AZ*; BENAVIDES, L; HARVEY, M; GIRIBET, G; SHARMA, P; University of Wisconsin, Harvard University, Western Australian Museum; *ontano@wisc.edu*

Disentangling Arachnid Systematics Through Rare Genomic Events

The evolutionary relationships among the orders of Arachnida has proven challenging despite the availability of a vast amount of genetic data. The placement of pseudoscorpions remains uncertain due to a phylogenetic artefact, long branch attraction, which leads to statistically inconsistent relationships among the arachnid orders. Analyses including a broad sampling of pseudoscorpion taxa spanning each of superfamily support the placement of pseudoscorpions as the sister group to scorpions. The sequential removal of basally branching lineages from analyses artificial increases the branch length of the order's basal branch, leading to support for the placement of pseudoscorpions as sister to the parasitiform ticks and mites due to long branch attraction. Alternative classes of phylogenetic data are a potential solution for reconstructing relationships where sequence data have not achieved topological stability. Rare genomic events serve as a data class to determine the relationship between pseudoscorpions and the rest of Arachnida. We investigated the signature of shared duplicated genes as phylogenetic characters as indication for a relation between pseudoscorpions with the arachnopulmonates (spiders, scorpions, and their allies), which are inferred to have undergone an ancient whole genome duplication. We sequenced the first developmental transcriptome of the pseudoscorpion *Conicochernes crassus* to investigate the incidence of duplicated genes shared by the arachnopulmonates. Our transcriptomic data show that pseudoscorpions retain many duplicated genes across a variety of disparate gene families. Analysis of gene trees recovered topologies consistent with a single shared genome duplication with arachnopulmonates, suggesting a close relationship with the pseudoscorpions.

84-5 ORBACH, DN*; BRENNAN, PLR; HEDRICK, BP; KEENER, W; WEBBER, M; MESNICK, SL; Texas A&M University- Corpus Christi, TX, Mount Holyoke College, MA, University of Oxford, UK, Golden Gate Cetacean Research, CA, Southwest Fisheries Science Center, CA; *dara.orbach@tamucc.edu*

Unique Coevolution of Genital Asymmetry and Lateralized Mating Behavior in A Mammal

Consistent lateralized mating behaviors have only been reported in one species of mammals. Male harbor porpoises (*Phocoena phocoena*) sexually approach females exclusively on the female's left side while hooking their lengthy penis around the female into her vaginal opening. We assessed the morphological symmetry and shape of post-mortem reproductive tracts of male and female harbor porpoises to understand the evolution of this unusual lateralized behavior. Two-dimensional geometric morphometrics of the vagina and three-dimensional models of the vaginal lumen and inflated penis tip were used to characterize and quantify genital shapes and assess the influences of asymmetry on overall genital shape. In 2D, there was substantial individual variation in vaginal shape that was not correlated with total body length. The vaginas exhibited significant fluctuation and directional asymmetry, suggesting the asymmetry is functional. The vaginal lumens were highly asymmetric, which was driven by complex 3D spirals and vaginal folds with deep recesses. These vaginal folds appear to physically obstruct the penis and curtail the depth of penetration. The asymmetric shapes of the penis tip of free-swimming harbor porpoises, excised penis tip, and vaginal lumen were remarkably similar. We suggest that the left-sided sexual approach of males enables the penis to deeply penetrate the vagina. We demonstrate that the reproductive anatomy of males and females and their lateral mating behavior have coevolved in harbor porpoises.

121-2 ORR, SE*; BUCHWALTER, DB; North Carolina State University; *seorr@ncsu.edu*

It's All About the Fluxes: Temperature Influences Ion Transport and Toxicity in Aquatic Insects

Many freshwater ecosystems are becoming saltier and/or warmer, but our understanding of how these factors interact and affect the physiology and life history outcomes of most aquatic species remain unknown. We hypothesize that temperature modulates ion transport rates. Since ion transport is energetically expensive, increases in salinity and/or temperature may influence ion flux rates and ultimately, organismal performance. Radiotracer ($^{22}Na^{+}$, $^{35}SO_4^{-2}$, and $^{45}Ca^{2+}$) experiments with lab-reared mayflies (*N. triangulifer*) and other field-collected insects showed that increasing temperature generally increased ion transport rates. For example, increasing temperature from 15°C to 25°C, increased $^{22}Na^{+}$ uptake rates by two-fold ($p < 0.0001$) and $^{35}SO_4^{-2}$ uptake rates by four-fold ($p < 0.0001$) in *Hydropsyche* sp.. Smaller changes in $^{22}Na^{+}$ and $^{35}SO_4^{-2}$ uptake rates were observed in *Isonychia* sp. and *Maccaffertium* sp., suggesting species-specific differences in the thermal sensitivity of ion transport. We further explored the influence of SO_4 challenge on mRNA expression of two SO_4 transporter genes (putatively Na-dependent and Na-independent SO_4 transporters in the SO_4 permease family). Expression of the Na-dependent SO_4 transporter was unaffected, whereas the expression of the Na-independent SO_4 transporter was increased 4.5-fold at the highest salinity (1300 mg/L SO_4) ($p < 0.05$), suggesting an efflux function. Finally, we demonstrated that the toxicity of SO_4 was influenced by temperature profoundly in a 96-hour bioassay. Under the saltiest conditions (1500 mg/L SO_4), mayfly survival was 78% at 15°C, but only 44% at 25°C ($p < 0.0036$). Conceivably, the energetic cost of osmoregulation in warmer, saltier environments may cause significant major ion toxicity in certain species of freshwater insects.

S4-13 ORR, TJ; New Mexico State University; *TeriOrr@nmsu.edu*

Round Table Discussion for Reproduction: the Female Perspective from an Integrative and Comparative Framework

To conclude our symposium on female reproduction from a comparative and integrative perspective we invite our participants as well as all SICB attendees to join in a roundtable discussion. The symposium itself focused on female reproduction from diverse avenues and we hope to collect a snapshot of perspectives that reflect this diversity. Several key questions will be addressed including: What are the key gaps in our knowledge regarding female reproduction? Where might ignoring the female perspective result in misguided conclusions? How can we bridge these gaps? What terminology is biased or otherwise antiquated and promotes misleading assumptions, ex: fertilization, egg? What alternatives can we provide, ex: conception, ovum? What are the issues with any alternatives? What are the next big questions in biology as they relate to the female perspective? Symposium organizers and participants will be encouraged to bring forth questions that have been posed throughout our sessions. Our goal is to make strides in refining terminology as well as outlining gaps in our knowledge that are of broad interest to integrative biologists.

S4-12 ORR, TJ*; HAYSSEN, V; New Mexico State University, Las Cruces, Smith College, Northampton; *TeriOrr@nmsu.edu*

Where now? Future directions in reproductive biology framed by the female perspective

Female reproduction is key for the success of sexually reproducing species. However, not only have females been understudied in many regards, but data have commonly been interpreted in the context of now-outdated social mores. As a summary to our symposium, we highlight gaps in our knowledge about female reproductive biology and provide a jumping-off point for discussing future research areas with a focus on a process: sperm storage, a morphological trait: genital evolution and life history theory: reproductive timing. We also discuss the promise of emerging methods such as micro-CT scanning, high-throughput sequencing, proteomics, CRISPR-Cas9 and viral vector technology, and big-data analyses for yielding insights into previously cryptic processes and features. For example, in mice DNA sequencing via ChIP-Seq is already unveiling how epigenetic interactions lead to sex differences in brain development- and holds promise for future work. Similarly, we discuss how new areas such as microbiome research are debunking dogmas such as the notion of the ‘sterile womb.' In light of NSF's Rules of Life Idea projects we highlight how female reproductive biology is well suited to studies that are ‘Predicting Rules of Life.' Studies of female reproductive biology will enable scholars to: 1) traverse levels of biological organization from the ovum, to reproductive proteins, vaginal and uterine morphologies, physiology, mating behaviors, whole-organism performance, ecology, and population structure; 2) discover generalizable rules such as the nature of trade-offs females navigate to reproduce when both sufficient energy and mates are available; and 3) predict the impacts of changes in biological systems such as in the reliability of changing environmental cues used to time reproduction.

S4-1 ORR, TJ*; HAYSSEN, V; New Mexico State University, Las Cruc, Smith College, Northampton, MA; *vhayssen@smith.edu*
Introduction
This symposium is about reproductive biology from the female perspective, but what do we mean by the female perspective? Most obviously, since we have chosen female speakers, one meaning is that the female perspective is the view of female scientists. Our diverse speakers are from a range of academic ranks (post-docs to chaired professors) and study a range of animal taxa from insects to mammals. More importantly, we want to examine reproductive biology from the perspective of female organisms themselves. What happens when we examine social behavior, physiology, or ecology strictly from the viewpoint of females? In many cases the female-centric perspective will alter our prior interpretations. For example, with DNA fingerprinting, differences between genetic and behavioral mating systems became obvious. We realized that assessing parentage (the ultimate basis of categorizing mating systems) using male-mating strategies resulted in flawed conclusions; in fact, sperm selection leading to conception is more important than mating per se. This is an example of how behavioral ecology might change its interpretations if we examine systems from the female perspective. Another example comes from studies of whole-organism performance –whereby jumping, running, and swimming have been measured in males with a deliberate removal of females and the major facet of their physiology, i.e. reproduction. However, female biology may actually set the limits of performance given the extra weight and changes in body shape required for reproduction. For instance, new insights into metabolic ceilings arose from examining energy consumption during lactation. These changes in how we understand behavior and physiology are relevant across diverse taxa. Our speakers will continue the exploration of ways in which our framework shifts when we use a female perspective.

87-5 ORTEGA-JIMENEZ, VM*; SANFORD, CP; Kennesaw State University, Kennesaw, GA; *ornithopterus@gmail.com*
Beyond the Kármán Gait: Knifefish swimming responses to complex wakes shed by a free oscillating cylinder
Tropical fish such as knifefish are commonly challenged by unsteady flows associated with natural and artificial structures. A classical example, broadly used in animal locomotion research, is the Kármán vortex street: a regular pattern of counter-rotating eddies downstream produced by a rigid body. However, natural structures in rivers (e.g., plants, submerged logs, rocks) are relatively loose, and tend to oscillate due to a phenomenon called vortex-induced vibration. These vibrations result in a more complex pattern of vortex shedding that can have pronounced effects on fish locomotion. We investigated the 3D kinematics and swimming behavior of the black ghost knifefish (*Apteronotus albifrons*, N=7) in response to the complex wake of a free oscillating cylinder, a fixed cylinder and laminar flow. Flow conditions were characterized using PIV. We found that knifefish maintain position with minimal movements in the recirculation zone of a fixed cylinder, using their ribbon and pectoral fins to occasionally regain stability. In contrast, for the oscillating treatment individuals actively swim using their ribbon and pectoral fins, as well as body bending to maintain position behind the moving cylinder. We observed that in some individuals, the body oscillated in or out-of-phase depending on downstream location. A model knifefish (reconstructed using photogrammetry and 3D printed) was placed at different downstream distances from an oscillating cylinder to verify passive movements. The fish model located just downstream from the cylinder oscillated out of phase with the moving cylinder, but oscillated in phase when placed one-cylinder diameter downstream. Thus, vortex-induced vibrations in bluff bodies create an unsteady flow environment that is more challenging for animals, than Kármán vortex streets.

98-7 ORTON, RW*; SCHIELD, DR; NIKOLAKIS, ZL; PERRY, BW; DEMUTH, JP; MACKESSY, SP; SMITH, CF; MEIK, JM; CASTOE, TA; University of Texas at Arlington, University of Northern Colorado, Tarleton State University; *richard.orton@uta.edu*
The landscape of diversity and divergence across genomes highlights links between genome structure and evolution in the formation of genomic islands
A central goal of evolutionary biology is understanding how genetic differentiation is accumulated and structured across genomes during lineage divergence. Recent advances in the interrogation of genome-wide patterns of variation in divergent lineages have revealed heterogenous landscapes of diversity and differentiation that are marked by genomic ‘islands' of high population differentiation set against a genomic background of low population differentiation. Although genomic ‘islands' are generally expected to show greater resistance to introgression, the relative contributions of various evolutionary processes to the formation of genomic ‘islands' are poorly known. Here, we sampled genomic variation using RADseq sampling from three pairs of rattlesnake lineages, and interpreted these data using a chromosome-level reference genome for the Prairie Rattlesnake (*Crotalus viridis*) to compare patterns of variation, population genetic structure, and differentiation among genomic regions. Because macro-, micro-, and sex chromosomes differ in rates of recombination, we assessed each chromosome class individually. We then tested correlations between nucleotide diversity (pi), relative differentiation (Fst), and absolute differentiation (dxy) in order to infer the evolutionary processes underpinning lineage divergence. Our results illustrate the insight gained through interpreting population genetic variation using chromosomal genome assemblies, and provide links between genomic islands and the forces that contribute to their formation and persistence.

99-1 OSGOOD, A.C; SUTTON, G; ST.PIERRE, R; COX, S.M*; Mount Holyoke College, University of Bristol, Carnegie Mellon University, Penn State; *zanne@psu.edu*
More evidence against a force-velocity trade-off in dynamic lever systems
Levers impose a force-velocity trade-off. In static conditions, a larger moment arm increases a muscle's force capacity while a smaller moment arm enhances velocity at the end of the lever. However, muscle force is influenced by contractile velocity and fiber length. Additionally, the rate at which the muscle contracts is influenced by the inertial properties of the mass it accelerates. We hypothesize that these dynamic effects constrain the functional output of a muscle-lever system. We predict that there is an optimal moment arm for either force or velocity for any given muscle-lever configuration. Here we test this hypothesis by building and systematically modifying a simple lever system in OpenSim. The model consists of a mass on the end of a lever that pivots around a pin joint, driven by a Millard2012EquilibriumMuscle muscle with a non-compliant tendon. The muscle's moment arm was defined by the radius of a cylinder around which it wraps. We generated 3600 modifications of this model with different muscles with varying optimal fiber lengths, moment arms and starting normalized muscle lengths. For each model we simulated the motion that results from 100% muscle activation and extracted the maximum velocity of the driven mass as well as the total impulse applied to the mass from the onset of movement until the time of maximum velocity. In contrast to the common notion of a tradeoff between force and velocity in a lever system, we found that there was, instead, an optimal moment arm which maximized both velocity and total impulse. From this we conclude that in a dynamic lever system where muscle activation is held constant, there is no tradeoff between force and velocity.

36-4 OSMANSKI, AB*; JOHNSON, M; GONGORA, J; DENSMORE III , LD; RAY, DA; Texas Tech University, Dept of Biological Sciences, Lubbock, TX, University of Sydney, Sydney School of Veterinary Science, Sydney, Australia; *austin.osmanski@ttu.edu*

Genomic Signatures of Selection Detection Across the Order Crocodylia

Crocodylians are of considerable biological importance as the largest extant reptile and prevail as necessary components of healthy aquatic ecosystems worldwide. Understanding the evolutionary relationships among crocodylians is of vital importance for their conservation especially since many of the charismatic species within this order are listed as threatened or endangered by the ICUN Red List. Therefore, to better understand these organisms at a genomic level, we generated light-to-medium coverage Illumina data for 18 species of crocodylian and curated a comparative structural variant dataset while constructing reference-guided assemblies. Using the box-turtle genome along with multiple bird genomes as outgroups, we produced an array of shared single-copy orthologous genes among all species for selection detection. Putative genes under positive selection were identified and a Bonferroni correction was applied to increase conservativity. These data will improve our understanding of selection among crocodylians and provide a template for future investigation into their genomes.

5-1 OTHAYOTH, R*; THOMS, G; LI, C; Johns Hopkins University; *ratan@jhu.edu*

Animals and robots transition from more challenging to easier locomotor modes to traverse obstacles

Animals transition between multiple locomotor modes when traversing obstacles in complex terrain. However, the physics of such locomotor transitions are not well understood. Previous studies in our group of grass-like beam obstacle traversal observed that the discoid cockroach often pitches up when initially interacting with the beams (pitch mode). To traverse, the animal then either continues pushing down the beams with sustained pitching, i.e., continue to use the pitch mode, or transitions to roll mode by rolling the body into the gap between the beams. Curiously, whether the animal continues to use the pitch mode or transitions to the roll mode depends strongly on the stiffness of the beam obstacles. Here, we tested a robophysical model traversing beam obstacles with different stiffness and developed a potential energy landscape to understand these animal observations. We found that the system states were always strongly attracted to local minima basins on the potential energy landscape. Regardless of beam stiffness, the system was always more likely to transition from more challenging (higher minima) to easier locomotor modes (lower minima) on the landscape. At lower beam stiffness, the pitch local minimum was lower than the roll local minimum, i.e., the pitch mode was easier. Thus, pitch-to-roll transition did not occur. As beam stiffness increased, the pitch local minimum became higher than the roll local minimum, making the roll mode easier. Thus, the system was more likely to transition to the roll mode. These results from robophysical experiments were consistent with our animal observations. Our study revealed the physical principles governing the direction of locomotor transitions in complex terrain and is a step in establishing energy landscapes for locomotor transitions.

91-4 OTTER, K*; KATZ, P S; University of Massachusetts Amherst; *kotter@umass.edu*

Hunger state modulates the decision of a nudibranch to pursue or evade hazardous prey

Predators constantly make decisions about whether to pursue or evade prey, especially when their prey has the capacity to injure them. The nudibranch mollusc, *Berghia stephanieae* provides a special opportunity to study the neuroethology of predator pursuit and avoidance. Like many nudibranchs, it is a specialist predator, feeding exclusively on the sea anemone, *Exaiptasia pallida*. However, unlike other nudibranchs, it and its prey can be reared in the lab in large numbers facilitating experimentation on behavioral choice. When feeding, *Berghia* is repeatedly stung by the *Exaiptasia's* nematocysts and must decide whether to approach and feed or turn and evade. We characterized the feeding behavior and the probabilities of response to contact with the *Exaiptasia* in starved and sated animals to elucidate the neural mechanisms underlying the approach-avoidance decision making in this animal. The *Exaiptasia* can sting *Berghia* with its tentacles or with its acontia, structures with a higher concentration of nematocysts that are extruded as a threat response. The hunger state of the *Berghia* modulated their decision-making; hungry animals endured more stinging than sated animals. In response to contact with *Exaiptasia* tentacles, starved *Berghia* had a significantly higher probability of engaging with their prey than sated individuals, furthermore after contacting the *Exaiptasia* acontia, starved *Berghia* also had a significantly lower probability of an evasion response than sated animals. Moreover, starved animals spent a smaller proportion of time exploring the arena and more time feeding than sated animals. Thus, the choice of whether to pursue or evade is modulated by the animal's internal state; it seems that they make riskier choices when hungry. Future work will examine potential neural mechanisms for this cost benefit decision making.

105-4 OUFIERO, CE; Towson U; *coufiero@towson.edu*

Morphological evolution of the praying mantis (Mantodea) raptorial foreleg in relation to body size and depth perception

Mantises (Mantodea) are a group of 2600+ ecologically diverse species that all use raptorial forelegs for prey capture and processing. The mantis foreleg is comprised of the coxa, trochanter/femur, and tibia. During a feeding strike, extension of the coxa and trochanter/femur places the femoral and tibial spines in place for prey capture, which occurs when the tibia is flexed, trapping the prey in the spines. Variation in lengths of each segment may affect the mechanical advantage of the foreleg and influence feeding performance. While research on terrestrial, vertebrate locomotion has shown that variation in limb proportions have adaptively evolved across environments, much less is known about adaptive diversification of invertebrate feeding appendages. Furthermore, as feeding performance is influenced by the sensory system, few studies have examined the coevolution of sensory-motor structures. Using 97 species of mantises I examined foreleg diversification with a combination of methods, including ternary plots for morphospace visualization, phylogenetically informed allomteric relationships, and comparison of evolutionary rates of diversification. Furthermore, using head width as a proxy for depth perception, I examined the correlated evolution of foreleg diversity with depth perception. The results show that among the three segments of the foreleg, the tibia is the smallest, most diverse, and has the highest rate of evolution after body size corrections. Furthermore, while all foreleg segments were related to head width, head width explained the most variation in tibial length. The results suggest a potential adaptive functional role of the length of tibia related to the velocity or force produced in this second class mechanical lever. Furthermore, results from this study support distinct ecomorphs of mantises, as several independent evolutions to grass mimicry evolve similar morphologies.

4-3 OZALP, MK*; MILLER, LA; STRICKLAND, C; UNC, Chapel Hill, NC, UT, Knoxville, TN; *mkoz@live.unc.edu*
PLANKTON DISPERSION THROUGH VEGETATIVE SEABED WITHIN COMPLEX FLOW ENVIRONMENTS
The movement of plankton is often dictated by local flow patterns, particularly during storms and in environments with strong flows. Reefs, macrophyte beds, and other immersed structures can provide shelter against washout and drastically alter the distributions of plankton as these structures alter and slow the flows through them. Advection diffusion and agent-based models are often used to describe the movement of plankton within marine and freshwater environments and across multiple scales. Experimental validation of such models of plankton movement within complex flow environments is challenging, however. In this study, we experimentally investigate plankton dispersion through various, rigid macrophyte models in complex flow environment at the scale of tens of centimeters. We use *Artemia* spp., or brine shrimp, as a model organism given their availability and ease of culturing. Experiments were conducted within a flow tank with simplified physical models of macrophytes. These simplified models were 3D-printed arrays of cylinders of varying heights and densities. *Artemia* nauplii were injected within these arrays and their distributions over time were recorded with multiple video recorders. The detailed three-dimensional flow fields were quantified using computational fluid dynamics and validated experimentally with 2D particle image velocimetry. Complementary agent-based simulations of the movement of brine shrimp through these structures were also performed. The results show that increasing density and the height of the macrophyte bed drastically increases the average time it takes the plankton to be swept downstream. It was also observed that some brine shrimp can entirely avoid being swept away in the presence of macrophyte model. This phenomenon was observed only in the close vicinity after the model and only at the bottom of the flow tank, where the effect of the boundary layer is significant. Moreover, more brine shrimp stayed attached with the increased density and height and the zone of attachment extended, as well. However, no shrimps could avoid being swept away in the model. Agent-based models of brine shrimp that move with random motion and are advected with the flow show similar trends.

52-1 PADDA, SS*; JOHNSON, DJ; GLASS, JR; STAHLSCHMIDT, ZR; U Pacific, Ariz State U; *s_singh40@u.pacific.edu*
Alter Investment or Conserve? Assessing animal strategies to limit costs from concurrent weather extremes
Climate change models predict an increase in the co-occurrence of heat waves and water limitation (e.g., drought). Both of these stressors can independently impact an animal's resource (energy or water) balance, which is tightly linked to survival and reproduction. Yet, the interactive (e.g., additive or synergistic) costs of heat wave and water limitation to animals is poorly understood. Animals experiencing heat wave and/or water limitation may employ two general strategies to limit costs to resource balance. Stressed animals may use a resource conservation strategy via shifts in physiology (e.g., reducing metabolic rate to conserve energy or altering integument to reduce water loss) or behavior (e.g., reducing behavioral activity to limit energy use and water loss). Second, stressed animals may alter their resource investment strategies whereby resources are divested from one trait to maintain investment into another trait. We used a factorial design on fasted wing-dimorphic crickets (*Gryllus lineaticeps*) to examine the independent and interactive costs of a field-parameterized heat wave and water limitation. We determined survival, energy balance and loss (body mass and metabolic rate, respectively), water balance and loss (total water content and evaporative water loss rate, respectively), behavioral activity, and investment into reproduction (gonad mass), locomotion (flight muscle), and immune function (total phenoloxidase activity). Together, our results will clarify the costs of multiple stressors to several levels of biological organization (from life history to behavior and physiology), and reveal complexities underlying general strategies employed during resource-related stress.

96-8 OZKAN-AYDIN, Y*; GOLDMAN, D I; BHAMLA, M S; Georgia Institute of Technology; *yaydin6@gatech.edu*
Collective Behavior of Worm Blobs
Aggregate formation and clustering are common behaviors observed across taxa and can facilitate the survival of the collective (Allee, 1978). Here we study the aggregation of blackworms (*Lumbriculus variegatus*) into large ensembles of entangled, living "blobs" composed of thousands of worms knotted together. To understand the mechanism and advantages of aggregation in these worm blobs, we systematically expose them to different environmental stresses including evaporation, light, temperature and starvation. The diameter of the worm blob can be controlled by both light stimulus history and light intensity. At low light intensity the blob dilates; conversely, increasing the light intensity contracts the blob and leads to more entangled and tightly packed state. This behavior also affects the collective movement under thermal stress. Under high light intensity (>1500 Lux) we find that a 5 g (600 hundreds) worm blob placed under a linear temperature gradient between 15 to 50°C stay as a blob and move collectively to the cold side at speeds of 0.35 ± 0.001 cm/min. In contrast, if the light intensity is reduced to 400 lux, the worm blob dissipates and individual worms crawl to the cold side with a speed of 0.38± 0.01 cm/min. We find that the number of surviving worms increases as they move as a blob. Finally, we show that this worm blob can also navigate structured environments (mazes) to survive from starving. Individual worms search the maze and the worm blob finds the shortest path to the food source. We hypothesis that the exchange of information between individuals and the perception of nutrient concentration released from a food source determines the direction of migration.

114-5 PAEZ, L*; MELO, K; SAKAR, S; IJSPEERT, AJ; EPFL; *laura.paez@epfl.ch*
Kinematic and dynamic analysis of the mosquito larvae gait
Although the elongated morphology of mosquito larvae shares similarities with several other aquatic organisms, many of which swim under comparable hydrodynamic conditions using undulatory gaits, their locomotion consists of unsteady sideways strokes of the paddle-like end of their articulated body. This pulls back a large volume payload (the insect thorax) located at the other end of their body. We hypothesize that such a gait may help transport larger payloads at certain hydrodynamic regimes, as compared to undulatory swimming gaits. We analyzed the kinematics of larvae motion using videos, to break down their gait into different instances of thrust generation. Previous studies explain the drag-based thrust generated solely by the paddle motion. However, these studies overlook other important inertial thrust contributions. We identified translations of the center of mass due to changes of the body configuration across the stroke time, as well as body rotations due to angular momentum conservation, that enhance the paddling action by conveniently reorienting the body at each stroke. To this end, we created a model that faithfully captures the kinematics of the larvae gait in a form of a large amplitude, small wavelength traveling wave along the body, giving us the possibility to track the center of mass motion using different body segment mass properties. This opens questions about the role of discrete articulated segments present on the larvae's body, compared to the continuous body in undulatory swimmers, the role of a passive/active paddle in comparison to tail fins, and how the payload payload impacts the gait's cost of transport to favour unsteady gaits over undulatory ones. To make such comparisons, we complemented our model with a physical robot to experimentally test and validate our observations on living larvae.

21-8 PAGGEOT, LX*; GOSLINER, TM; California Academy of Sciences; *lpaggeot@calacademy.org*

Stinger Thieves: Nematocyst Acquisition Process in Aeolid Nudibranchs

Nudibranchs encompass over three thousand species around the world, and still counting. One subgroup of nudibranchs is called aeolids: a specialized group of nudibranchs that are capable of stealing nematocysts from their cnidarian prey and using them as part of their own defensive mechanism. Nematocysts are also known as "explosive cells", a variety of special organelles that are present in cnidarians. The relationship between the nematocysts in nudibranchs and their cnidarian prey remains unclear due to the variation and diversity within nematocysts. Earlier studies also show a discrepancy in the results, warranting a project looking at different species of aeolid nudibranchs and their cnidarian prey. My project focuses on comparing nematocyst content in multiple aeolids and cnidarians along the Californian coast to examine specificity of nematocyst selection and retention within Nudibranchia. Preliminary results show that different aeolid nudibranchs vary in the diversity of nematocysts they retain, and these only represent a subset of nematocysts found in their prey.

70-3 PALAVALLI-NETTIMI, R*; THEOBALD, JC; Florida International University, Miami, FL; *rpalaval@fiu.edu*

Light intensity and eye size dependent spatio-temporal visual abilities in Drosophila melanogaster

The fruit fly *Drosophila melanogaster* is sensitive to light and prefers certain light intensities. But lab-reared flies are often tested for vision in bright light conditions to obtain the best response. Similarly, scarce feeding during the late larval stage, which is common in nature, can lead to smaller flies contributing to a wide range of body and eye sizes which are not observed in lab colonies fed ad libitum. Flying with smaller eyes and under dimmer light conditions is challenging due to reduced signal-to-noise ratio affecting visual behaviors. To better understand the visual capabilities of flies in nature, it is thus important to study flies of different eye sizes and under different light intensities. In this study, we use a virtual reality flight arena and moving sinusoidal gratings to test how spatial acuity, temporal acuity and contrast threshold are affected at different light intensities in female flies that vary in eye size. We also investigate vision in often neglected male fruit flies under different light intensities and compare them to that of females. We show that as light intensity drops from 50.1 lx to 0.3 lx, it leads to reduced spatial acuity (females: from 0.1 to 0.06 cycles per degree, CPD, males: 0.1 to 0.04 CPD) and temporal acuity (females: from 50 Hz to 10 Hz, males: 25 Hz to 10 Hz), and higher contrast detection threshold (females: from 10% to 29%, males: 19% to 48%). We find no major sex-specific differences in visual abilities after accounting for eye size variation. While vision in both small (eye area 0.1 to 0.17 mm^2) and large flies (0.17 to 0.23 mm^2) reduce at 0.3 lx compared to 50.1 lx, small flies suffered more (spatial acuity: 0.03 vs 0.06 CPD, contrast threshold: 76% vs 57%, temporal acuity: 5 Hz vs 10 Hz). These results have implications to many visual behaviors in flies.

40-7 PALECEK-MCCLUNG, AM*; BLOB, RW; Clemson University; *apalece@g.clemson.edu*

Wading through water: The influence of water depth on the locomotion of the Chilean Flamingo (Phoenicopterus chilensis)

One of the factors impacting the diversity of locomotor modes in animals is the habitat in which movements are performed. Environments like water and land impose different physical demands and, as a result, many species that operate in both environments use a distinct mode of locomotion in each; for example, swimming in water versus walking on land. However, many species that move between land and water may continue to use a terrestrial mode of locomotion in aquatic environments. If animals are not entirely submerged, such behaviors are termed wading, and are present in a variety of taxa including amphibians, reptiles, mammals, and birds. As animals move through water of increasing depth, species with long legs may be able to lift their feet above the water surface to reduce drag that could slow their performance. However, there may also be a critical depth, above which it becomes awkward to raise the foot above the surface, and kinematics again resemble terrestrial patterns of movement. To test these predictions, head, body, and limb kinematics of the long-legged Chilean flamingo (*Phoenicopterus chilensis*) were measured as birds walked through increasing depths of water in a zoo enclosure. A variety of kinematic changes occurred across environmental conditions. As flamingos moved through deeper water, they showed a combination of slower movements with mass concentrated closer to the body that may help to increase stability as hindlimb angular excursions became more exaggerated. Although a critical depth at which wading kinematics began to resemble those used in terrestrial habitats was not identified over the range of depths tested, our results show that wading birds can implement a range of kinematic strategies to enable successful movement through different water depths.

51-4 PALERMO, NA*; SIDDIQUI, SG; THEOBALD, JC; Florida International University; *npale005@fiu.edu*

Drosophila melanogaster uses its regional attention to maxamize spatial information during flight.

Fruit flies rely heavily on their visual field to stabilize flight. The images projected onto their retinas are only as useful as the amount of information they provide. The spatial information capacity of the eye (H) is a measure of how many unique images can be drawn onto the eye and therefore describes the usefulness of images presented onto it. H depends on endogenous factors of the eye but also on the image source. Dim, low contrast, or fast-moving images all result in lower H. Flies recover this lost H via neural pooling but here we explored how attention shifting can also recover H. We found that flies actively shift attention to predictably slower moving regions as light levels decrease. We also found that the eye is passively designed to respond stronger frontally under low contrast conditions where images would likely be moving slower. Both these attentional strategies would maximize H under sub optimal flight conditions.

45-5 PARTRIDGE, CG*; MACMANES, MD; KNAPP, R; NEFF, BD; Grand Valley State University, University of New Hampshire, University of Oklahoma, University of Western Ontario; *partridc@gvsu.edu*

Brain transcriptional profiles of alternative reproductive tactics in bluegill sunfish

Bluegill sunfish are a classic system for studying male alternative reproductive tactics (ARTs). In this species, there are two life histories: parental and cuckolder, encompassing three reproductive tactics, parental, satellite, and sneaker. The parental life history is fixed, whereas within the cuckolder life history individuals appear to transition from the sneaker to the satellite tactic as they grow. We used RNAseq to identify differentially expressed transcripts in the brain of male ARTs and females during spawning. Sneaker males had higher levels of gene differentiation compared to the other two male tactics. Specifically, sneakers males exhibited high expression in ionotropic glutamate receptor genes, which may be important for working spatial memory while cuckolding parental males. We found expression differences in several candidate genes previously identified in other species with ARTs, suggesting some conserved pathways influencing these behaviors.

16-3 PASK, GM; Bucknell University; *g.pask@bucknell.edu*

Working to Learn: Applying Labor-Based Assessment to Scientific Writing and Laboratory Courses

There is a growing concern in higher education that students are focusing too much on grades and too little on their own learning and growth. Not only does grading for accuracy inadequately reflect a career in science, but it can disadvantage students with different backgrounds who may be unfamiliar with how to "play the game" of the education system. Across several disciplines in higher education, assigning grades to students based on their effort has shifted the focus to learning and self-improvement as well as created a more equitable and inclusive classroom. I've incorporated several aspects of labor-based assessment into my upper-level scientific writing course, where students routinely engage in a variety of writing assignments that are graded on completion instead of conforming to my own rubric. Students have appreciated the freedom to take risks in their writing without being penalized by point reductions and enjoyed having more ownership over their writing. In my laboratory course, students work toward achieving specific goals throughout the semester that prioritize technical mastery, experimental design, data analysis, and a peer learning environment. In evaluations and self-reflections, students found this goal-oriented approach to be very effective in their development as scientists, and it mirrored the types of experiences they hoped for in joining research labs. For both classroom and laboratory contexts, I present labor-based assessment as an approach to encourage self-motivated learning in all students regardless of their educational background.

18-6 PAYETTE, WI*; RICHTER, MM; HODINKA, BL; PULLUM, KB; ASHLEY, NT; Western Kentucky University, Simon Fraser University, University of Pennsylvania; *wesley.payette468@topper.wku.edu*

Effect of sleep on loss on parental care in Arctic-breeding songbirds

Sleep loss is well known to impair cognitive function, immunological responses, and general well-being in humans. However, sleep requirements in mammals and birds may vary dramatically, especially with changes in environment. In circumpolar regions with continuous light, sleep requirements may be little, particularly in breeding birds. The effects of sleep loss on several fitness parameters were examined in two species of Arctic-breeding passerine birds: Lapland longspurs (*Calcarius lapponicus*) and snow buntings (*Plectrophenax nivalis*). Adult males were implanted during the nestling phase (4 days post-hatch) with osmotic pumps containing an anti-narcolepsy drug, modafinil, to induce sleep loss for 72 h. We measured nestling weights on day 2 and day 7 following hatching. In addition, we conducted 1 h observations of nestling feeding rates on day 6 post-hatch. Recent data show that adults undergo a 4-5 h quiescent period between 0000h and 0500h. We predicted that further inhibition of sleep may temporarily increase feeding rates, but eventually lead to decreased parental care and slower nestling development from birds needing to sleep after pharmacological inhibition. Alternatively, as high-arctic species are adapted to continuous light throughout their breeding season, mechanisms may exist that allow them to function normally despite loss of sleep.

137-5 PEPPER, H E*; PARTIN, A M; JENKINS, M S; ROWLAND, J F; BURGHARDT, G M; University of Tennessee, Knoxville; *hpepper@vols.utk.edu*

Responses of Juvenile Eastern Garter Snakes (Thamnophis sirtalis) to Own, Littermate, and Control Chemicals

Chemical cues and signals are essential components of numerous behaviors among squamate reptiles, especially snakes. Tongue flicking allows transfer of chemical cues to the vomeronasal organ and the accessory olfactory bulb. Past studies have suggested that several species of snakes can discriminate chemicals deposited by themselves, conspecifics, or clean controls. Is this a measure of self-recognition? Most studies have used visual recognition, using a mirror. However, animals relying on different types of cues may use non-visual means of self-recognition. Prior snake studies, while suggestive, lacked controls, such as for diet and genetics, and video recording. We carried out a study on 24 juvenile eastern garter snakes, Thamnophis sirtalis, with an even sex ratio, from a single litter. We manipulated substrate chemicals in test arenas using clean or previously occupied cage liners and measured the frequency of tongue flicking and general activity. Each snake was tested under four conditions: one's own substrate, substrate of a same sex littermate fed the same or different diet (fish or worm), or a control clean substrate. Trials lasted 30 minutes, were video-recorded, divided into three 10-minute segments, and both tongue flick and activity counts tallied for each segment. We found that tongue flick and movement rates were consistently lower in the own chemical vs the control condition, replicating prior findings. We also found sex and diet differences with regard to tongue flick rates to own vs conspecific chemicals of snakes fed identical diets. These appear to be the first data showing sex differences pre-reproductively.

73-4 PEREVOLOTSKY, T*; GENIN, A; HOLZMAN, R; Tel Aviv University, Hebrew University of Jerusalem; *taltal.pere@gmail.com*
Work That Body: Thrust generated by the fins and body contributes to the feeding success of herbivorous reef fish
Herbivorous fish feed by biting, tearing or scraping algal material off the substrate. Due to their neutral buoyancy, fish feeding off hard surfaces may experience a recoil force pushing them backwards as they bite their food. To successfully detach prey items from hard substrates, fish need to constantly generate thrust in order to maintain contact with the substrate and pull the prey away. However, studies on adaptations for herbivory in fishes have hitherto focused on the jaws and teeth, neglecting the role of thrust-generating mechanisms. We hypothesize that these fish coordinate body and fin movements with mouth kinematics to facilitate algal removal. We used an underwater video system composed of two synchronized high-speed cameras, to observe the feeding kinematics of two *Zebrasoma* species *in situ*, in the coral reef. The system provided accurate 3D kinematics of the fish's mouth, fins and body, while a synchronized load cell recorded the forces exerted by the fish while feeding from a feeding plate. We found that bites were characterized by stereotypic and coordinated movements of the mouth, head and fins. Fish opened their mouth when approaching the feeding plate, reaching peak gape and often starting to close the mouth before initiating contact with the plate. Sideways head flicks accompanied almost all the bites. Upon mouth closing on the algae, fish swung their head laterally while moving their pectoral fins forward. This coordinated movement exerted a pulling force that was used to tear the algae from the substrate. Our results show that thrust generating mechanisms play a crucial role in the feeding success of herbivorous fish and suggest that adaptations for hard surface feeding expand beyond teeth and jaws.

79-3 PEREZ, JH*; TOLLA, E; DUNN, IC; MEDDLE, SL; STEVENSON, TJ; University of Glasgow, Roslin Institute, University of Edinburgh, Roslin Institute, University of Edinburgh; *Jonathan.Perez@glasgow.ac.uk*
Neuropsin and VA-opsin both facilitate photoinduction of avian seasonal breeding
Avian seasonal breeding has long been tied to the seasonal change in photoperiod in a number of temperate zone species. Unlike mammals, detection of light cues has been shown to occur independent of both the eyes and pineal glands via extra-retinal photoreceptive opsins located in the medial basal hypothalamus. To date, the precise identity of the specific opsin types and populations responsible for the photoinduction of seasonal breeding remains unresolved. Based on brain localization and light spectra profiles two potential candidates have emerged for the detection of light cues with respect to breeding; Neuropsin (Opn5) and Vertebrate Ancient Opsin (VA-opsin). Utilizing recent developments in viral vector technology we have silenced Opn5 and VA-opsin expression independently and together in the medial basal hypothalamus of Japanese Quail (*Coturnix japonica*) prior to photostimulation by long days (18L:6D). Body weight and cloacal gland volume was measured weekly for 4 weeks following photostimulation, a period sufficient for un-manipulated animals to reach reproductive condition. We found that RNA inhibition of Opn5 or Both showed an increase in mass gain rate when compared to VA only and control individuals. All three silencing treatments (Opn5, VA, Both) displayed reduced rates of cloacal gland growth (K) compared to control birds suggesting opsin silencing decreased the rate of hypothalamus-pituitary- gonadal (HPG) axis activation. Our data suggest that both Opn5 and VA-opsin play a key role in the activation of the reproductive axis in response to photostimulation and seasonal mass gain may be controlled via partially independent pathways from the HPG axis. Research was funded by the Leverhulme Trust and BBSRC (BB/P013759/1).

36-5 PERRY, BW*; SCHIELD, DR; MACKESSY, SP; CASTOE, TA; University of Texas Arlington, Arlington, TX, University of Northern Colorado, Greeley, CO; *blair.perry@uta.edu*
Mechanisms Driving Venom Gene Regulation in Rattlesnakes Revealed Through Integrative Analyses of Genome Structure and Function.
The evolution of novel organ systems necessitates the evolution of regulatory architecture to facilitate the function of the new organ. Understanding the processes by which this architecture evolves can provide broad insight into the evolution of phenotypic and physiological novelty and demonstrate previously unknown genomic features important for gene regulation. However, most organ systems are exceptionally complex and are driven by the coordinated regulation of thousands of genes located throughout the genome, making detailed interrogation of regulatory mechanisms exceedingly challenging. The snake venom gland represents an ideal system in which interrogate hypotheses about the evolution of novel regulatory architecture as it exhibits precise and high-magnitude regulation of a comparatively small set of principal genes, evolved relatively recently, and is physiologically distinct from other snake organ tissues. Here, we leverage the snake venom gland system and multiple integrative genomic analyses including Hi-C sequencing to investigate the evolution of venom gene regulatory machinery and provide new perspectives on the interplay between the evolution of regulatory sequences and the three-dimensional regulation of genome architecture in driving novel patterns of gene expression. Specifically, we identify transcription factors and regulatory pathways that have likely been co-opted from non-venom tissues and rewired to regulate venom gene expression, in conjunction with new insight into the role of three-dimensional organization and interaction of chromosomes during venom gene regulation.

9-5 PETERS, JM*; PETERSEN, KH; Cornell University; *jcbptrs@gmail.com*
Honeybee swarms use a flow-mediated pheromone signaling scheme to coordinate aggregation
Reproductive honeybee swarms form when thousands of workers fly from the nest with a queen, land on a nearby surface and aggregate around the queen to form a bivouac or cluster. The queen emits a volatile pheromone to attract the workers, but its dispersal is initially diffusion-limited. When a worker locates the queen it orients its head towards her, exposes the Nasonov scent gland on its abdomen and fans a jet of pheromone-laden air away from the queen with its wings. Other workers align with this airflow and propagate it. In this way, thousands of workers align with a collectively induced airstream which emanates from the queen's position. Workers toggle between "scent-fanning" and "scent-tracking" as they navigate upstream toward the queen. To better understand how individual behaviors scale up to generate this emergent aggregation scheme, we filmed the aggregation behavior of small artificial honeybee swarms and tracked the position, orientation and behavioral state of individual bees over time. Our preliminary results suggest that this phenomenon has two phases: (1) a rapid transition from disorder to order triggered by flow-mediated signal propagation and (2) a slow progression toward the queen which is structured by the emergent flow-pheromone field initialized in phase 1. This is an extraordinary example of how groups of individual organisms can sense and actuate their environment locally to achieve global coordination.

73-3 PETERSON, AN*; MCHENRY, MJ; Univ. of California, Irvine; *anpeter1@uci.edu*

Slow and steady wins the prey: The persistent predation strategy of the red lionfish (Pterois volitans)

The red lionfish (*Pterois volitans*) is a notoriously voracious predator and invasive species in the western Atlantic ocean. In contrast to its reputation, lionfish are plodding swimmers with no obvious advantages in predatory behavior. We performed behavioral experiments to determine the pursuit strategy of red lionfish as they pursued green chromis (*Chromis viridis*). Lionfish were able to capture prey with a high success rate on the first strike attempt (81%, n = 16), even though the median swimming speed of green chromis was 2-fold greater than the lionfish. Lionfish were persistent predators that employed a pure pursuit strategy by attempting to maintain a zero bearing. The swimming speeds of both fish decreased over time. The relatively slow approach by the lionfish may serve to prevent evoking evasive swimming by the prey. The prey decelerated significantly in the milliseconds before a successful strike occurred. Prey fast-start behaviors were rarely initiated prior to a strike (19%, n = 16) and were ineffective for survival. The simultaneous decrease in prey speed and rapid forward acceleration of the lionfish during suction feeding may increase the accuracy of the strike. In summary, lionfish persistently pursue their prey (up to 1 hour) and strike on the rare occurrences when the prey is moving slowing and within close proximity. Therefore, red lionfish appear to compensate for their slow locomotion with a predatory strategy that is characterized by persistence and opportunism.

62-3 PFEIFFENBERGER, JA*; TYTELL, ED; Tufts University, Medford, MA; *Janne.Pfeiffenberger@Tufts.edu*

Active muscular changes in the effective mechanical properties of fish bodies

Fish generate propulsive forces by bending their bodies back and forth using their muscles. During this motion, their bodies interact mechanically with the fluid around the fish. Therefore, the mechanical properties of their bodies are important for determining how effectively these muscle forces can be converted into whole-body propulsive forces. In this study, we measured the whole-body visco-elastic mechanical properties of pithed bluegill sunfish, *Lepomis machrochirus*. We used an oscillatory bending apparatus in which the tail of the fish was connected to a servomotor, while the other end was attached to a six-axis force transducer. Electrodes were inserted into the red muscle bands on the left and right side of the fish. The bodies were then bent back and forth at 3 Hz and an amplitude of 5 degrees while we altered muscle activation phases (-30%, -15%, and 0%) and duty cycles (20%, 30%, and 40%). Muscle activations were performed based on previous observations (underlined) made by Schwalbe et al. (2019). We aim to answer the following questions: 1) how do whole-body visco-elastic properties change between active and passive bending cycles?, and 2) do naturally observed muscle activation phases and duty cycles result in higher body stiffness? We found that body torques, local flexural stiffness, and local damping were highest at 0% phase, and were lowest at -30% phase. Passive stiffness and damping tended to be lower than active measurements. Surprisingly, changes in duty cycle did not result in any changes to the visco-elastic properties measured in this study.

S2-7 PHELPS, SM; PHELPS, Steven; University of Texas at Austin; *sphelps@utexas.edu*

Genetic and epigenetic influences on alternative tactics in the mostly monogamous prairie vole

Social behavior is among the most complex and variable of phenotypes. Optimal behaviors often depend on the strategies prevalent in a given population. In the case of the prairie vole, Microtus ochrogaster, a male transitions between a single and pair-bonded mating strategy when he is able to monopolize a female. The neuropeptide vasopressin plays a major role in the formation of such bonds, and the resulting strategies require coordination of brain regions involved in attachment, aggression, and memory. The expression of the vasopressin 1a receptor (V1aR) in the retrosplenial cortex (RSC), a brain region critical to memory, differs profoundly among prairie voles. Among males, RSC-V1aR predicts patterns of space use and sexual fidelity. We identified two alleles that drive differences in RSC-V1aR: a high allele that is favored in the context of intra-pair paternity, and a low allele that is favoring during extra-pair paternity. The alleles differ in several single-nucleotide polymorphisms located within a putative enhancer. The low-expressing allele contains significantly more CpG sites within this enhancer. Manipulations of developmental environments reveal that the low allele is more sensitive to both methylation and demethylation. Together the data suggest that the high allele shapes socio-spatial memory to promote mate-guarding, and is largely insensitive to developmental environment; the low allele, in contrast, seems to promote scarmble competition, but allows epigenetic modification of gene expression and behavior. We hypothesize that this represents an example of neuroendocrine reaction norms mediated by the abundance of CpG sites within a regulatory sequence.

50-6 PHILLIPS, JR*; HEWES, AE; SCHWENK, K; University of Connecticut, Storrs, CT; *jackson.phillips@uconn.edu*

Novel Air-breathing Modes in Anuran Tadpoles

The biomechanics of air-breathing in anuran tadpoles is virtually unstudied. Our previous work showed that surface tension prevents small tadpoles from breaching the surface to breathe. They overcome this constraint using a novel form of air-breathing, termed ‘bubble-sucking'. When bubble-sucking, a tadpole attaches its mouth to the under-surface of the water, expands its buccal cavity and pulls the surface into the mouth to create a bubble, which is then pinched off and compressed into the lungs. Tadpoles typically transition to breach breathing when large enough. In this study, we examined air-breathing mechanics in *Hyla versicolor* tadpoles over ontogeny using a combination of high-speed videography, paraffin histology, and statistical modeling. We found that *H. versicolor* differs from other species by never breach-breathing, even after growing large enough to do so. Rather, tadpoles transition from typical single bubble-sucks to ‘double bubble-sucks', which entail an initial bubble-suck, during which the lungs are emptied and the bubble expelled, followed by a second bubble-suck, in which a second bubble is compressed into the lungs. Air remaining in the buccal cavity is released from the mouth. Unlike single bubble-sucks, double bubble-sucks prevent the mixing of fresh and used air, increasing the efficiency of air-breathing. The shift from single bubble-sucking to double bubble-sucking occurs at approximately 6 mm body length. At this same body length we found a parallel transition in lung morphology, shifting from a low to high degree of vascularization. These results suggest that single bubble-sucks in *H. versicolor* are non-respiratory, possibly serving developmental or hydrostatic functions, whereas double bubble-sucks provide a derived, efficient mechanism of gas exchange in *H. versicolor*.

22-1 PHIPPS, N*; STEIN, LR; HOKE, K; Colorado State University, University of Oklahoma; *Nathan.Phipps@colostate.edu*
Genetic Background and Sexual Experience Jointly Determine Courtship Strategy
Animal mating behavior is influenced by both genetic background and lifetime experience. We sought to investigate how genetic adaptations to environmental stressors interact with events within an organism's lifetime to alter behavior. Reproductively isolated populations of Trinidadian guppies (Poecilia reticulata) occur in environments with either high or low predation rates. Evolutionary history with predators influences many phenotypes, including male courtship strategy. We observed male guppies from high predation, low predation, and intercross populations in their first encounter with a female. After 24 hours, we repeated the mating encounter to observe differences in mating strategy. We recorded occurrences of a variety of courtship behaviors in these encounters to determine how the effect of sexual experience on courtship strategy is influenced by population predation history. Our results describe the extent to which heritable factors contribute to learning in guppies. Follow-up experiments will investigate specific genetic loci which may influence mating behavior.

121-1 PIPES, BL*; NISHIGUCHI, MK; New Mexico State University; *nish@nmsu.edu*
mCherry-pHLuorin Tagging Illuminates the Role of Light Organ pH Modulation in the Vibrio fischeri-Euprymna scolopes Symbiosis
The bioluminescent marine bacterium *Vibrio fischeri* has been used to study mechanisms of environmental specificity in mutualistic associations with animal hosts. *V. fischeri* colonizes the light organ of sepiolid squids (Cephalopoda: Sepiolidae) and produces luciferase-based light which provides ventral counter-shading camouflage for the squid. Low pH levels may cyclically develop within the colonized light organ as a result of diurnal *V. fischeri* growth. Adaptation to such stressful conditions may provide *V. fischeri* a competitive advantage in colonizing the light organ. To investigate this phenomenon, we are developing novel methods of directly assaying pH within the colonized light organ of the Hawaiian bobtail squid, *Euprymna scolopes*. Previously developed *V. fischeri* strains containing a pH responsive ratiometric GFP derivative (pHLuorin) have shown promise as a fluorescent pH biosensor enabling the determination of both cytoplasmic and extracellular pH *in vitro*, but have constrained utility for assaying pH within the light organ due to the necessity of using uncommon fluorescence microscopy excitation/emission filter sets. To negate this limitation, new strains have been developed using a ratiometric mCherry-pHLuorin fusion protein in lieu of the standard pHluorin protein. These can be used to assay pH via fluorescence spectrometry, microscopy, and flow cytometry using standard red/green filter sets, while providing equivalent levels of sensitivity. The use of these novel biosensors in the lumen of the light organ will allow us to determine the extent of cyclic pH fluctuations as a determining factor in establishing successful colonization by *V. fischeri* in sepiolid squids.

95-1 PLAKKE, MS*; MESLIN, C; ARIKAWA, K; CLARK, NL; MOREHOUSE, NI; University of Kansas, INRA, SOKENDAI, University of Utah, University of Cincinnati; *mplakke@ku.edu*
A recent, lineage-specific, co-option event within the female reproductive tract of the Cabbage White butterfly, Pieris rapae L.
While reproductive traits are known to be some of nature's most rapidly evolving traits, investigations of this rapid evolution have traditionally focused on male reproductive traits. Females have been commonly viewed as passive participants in sexual reproduction, despite increasing evidence that female genitalia and proteins evolve at rates comparable to those documented in males. To better understand the rapid evolution of female reproductive traits, and how such rapid evolution may contribute to reproductive isolation, we studied evolutionary divergence in female reproductive traits of the Cabbage White butterfly, *Pieris rapae*. In butterflies and moths, females possess a unique reproductive organ, called the bursa copulatrix, which functions to digest the male spermatophore. Crosses between recently isolated subspecies indicate a potential reproductive barrier involving reduced spermatophore digestion rates in hetero-subspecific crosses. These results imply that traits involved in spermatophore digestion may have diverged between these two subspecies. Expression analyses of male and female proteins involved in bursa-spermatophore interactions indicate that proteins specific to the spermatophore remain constant in expression between the subspecies. In contrast, the female proteases that digest the spermatophore differ dramatically in their expression. Additionally, we observed a unique co-option event in one subspecies, where a protease normally expressed during the larval stage was also expressed in the bursa. Taken together, these results indicate that female reproductive traits may, in some species, be more evolutionarily dynamic than male traits. Our work thus motivates more careful study of female reproductive traits and their role in the rapid evolution of reproductive barriers.

S1-3 POLITO, MJ*; MICHELSON, CI; MCMAHON, KW; Louisiana State University, University of Rhode Island; *mpolito@lsu.edu*
Advances in the use of biogeochemical markers to track the diets and movement of Antarctic marine predators
Quantifying the diets, foraging ecology, and at-sea distribution of wide-ranging marine predators is critical to understanding their ecological responses to recent environmental change and predicting species responses in the future. However, logistical, financial, and ethical constraints can often limit researchers' ability to directly measure these key life history characteristics in Antarctic marine predators. The analysis of intrinsic biogeochemical markers, such as stable isotopes, fatty-acids, DNA, and bioaccumulating contaminants, represent powerful techniques that provide proxies of the diets and movements of marine predators when they cannot be directly observed. These methods are based on the principle that consumers "are what and where they eat" with conservative transfer of biomarker compounds from the base of the food web to consumers across the food web. This presentation will briefly review recent advances in the use of biogeochemical markers in studies of Antarctic predator ecology. It will also highlight two case studies. The first study uses compound-specific stable isotope analysis of feather amino acids to evaluate the diets and migration patterns of penguins from the genus Pygoscelis during the winter months when they are away from their breeding colonies. The second study uses this same technique to examine the trophic responses of sympatric chinstrap (P. antarctica) and gentoo (P. papua) penguins from the Antarctic Peninsula to nearly 100 years of shared environmental change. These studies highlight the potential that intrinsic biogeochemical markers have in complementing traditional diet and tracking methods to significantly expand the spatial and temporal scope of Antarctic marine predator studies.

S10-7 POLLY, P.D.; Indiana University; *pdpolly@indiana.edu*
The landscape of adaptive landscapes: trade-offs between performance surfaces in space and time
An important component of fitness is the performance of a functional trait in its local environment. But environments vary spatially and temporally, and so too will the performance of the trait. The adaptive landscape of any given functional trait thus changes as an individual encounters different environments in its daily movements, as a local population experiences environmental change over time, as gene flow in a metapopulation crosses environmental gradients, or as descendant species colonize environments that are different from those occupied by their ancestors. Shifts in trait optima across these environmental boundaries creates a selectional trade-off that in some contexts favors a compromise trait value and in others changes the rate and direction of selection on the trait. Here I present a recently developed approach for modeling the effect of such trade-offs on the evolution of multivariate phenotypes. It uses geometric morphometrics to construct a continuous phenotypic space that defines the axes of the adaptive landscape. Differences in performance of phenotypes across that space are assessed using computational tools like finite element analysis (FEA) and computational fluid dynamics (CFD) or experimental strategies to estimate an adaptive landscape for each environmental situation. Using a combination of computer simulations and new data I show how maximum likelihood can be used to estimate the balance of environments that is most consistent with any given realized phenotype. I also show how this approach can be used in to predict the net phenotypic change expected from a shift in environment.

27-1 POMERANTZ, AF*; KISHI, Y; PINNA, C; ELIAS, M; PATEL, NH; University of California Berkeley, California Institute of Technology, Museum National d'Histoire Naturelle, Museum National d'Histoire Naturelle, Marine Biological Laboratory; *pomerantz_aaron@berkeley.edu*
Making it Clear: Evolution and Development of Wing Transparency in Lepidoptera
The wings of butterflies and moths (Lepidoptera) are typically covered with thousands of flat, overlapping scale cells that endow the wings with colorful patterns and make them predominantly impenetrable to light. Yet numerous species of Lepidoptera have evolved transparent wings that allow light to pass through. Transparency requires low absorption and reflection, as well as low scattering of light, and these constraints are often difficult to fulfill for terrestrial organisms. This is particularly due to the large difference between the refractive indices of living tissues (n=1.5) and air (n=1) resulting in significant surface reflections. As a solution, some Lepidoptera have evolved modified scales so that the underlying wing membrane is exposed, and in some cases added elaborate nanostructures on the surface that gradually change the index of refraction and, as a result, give the wing anti-reflective properties. Here we set out to explore the evolutionary history, morphological diversity, and development of wing transparency in Lepidoptera, and find that clearwing traits arose numerous times independently. To probe features of clearwing development, we apply confocal and transmission electron microscopy to generate a description of scale cytoskeletal organization in the glasswing butterfly, Greta oto. Finally, we compile optical and scanning electron microscopy of clearwing scale types and surface nanostructures, highlighting a range of novel and structurally diverse solutions to achieve anti-reflection properties. These findings give us additional insight into the evolution and development of naturally organized micro/nanostructures and may provide bioinspiration for design and engineering of new anti-reflective materials.

68-2 POOLE, AZ*; BAILEY, GF; Berry College; *apoole@berry.edu*
GTPases of Immunity Associate Proteins (GIMAP) gene expression in response to induction of apoptosis and autophagy in the sea anemone Exaiptasia pallida
Coral reefs, one of the world's most productive and diverse ecosystems, are currently threatened by a variety of stressors that result in increased prevalence of both bleaching and disease. Therefore, understanding the molecular mechanisms involved in these responses is critical to mitigate future damage to the reefs. One group of genes that are potentially involved in cnidarian immunity and symbiosis are GTPases of Immunity Associated proteins (GIMAPs). In vertebrates, this family of proteins is involved in regulating the fate of developing lymphocytes and interacts with proteins involved in apoptosis and autophagy. Since both apoptosis and autophagy are processes previously shown to be involved in cnidarian symbiosis, the goal of this research was to determine the role of cnidarian GIMAPs in these cellular processes using the sea anemone *Exaiptasia pallida*. To do so, GIMAP genes were characterized in the *E. pallida* genome and changes in GIMAP gene expression were measured using qPCR in response to chemical induction of apoptosis and autophagy. The experiment was conducted in both symbiotic and aposymbiotic anemones to account for the effect of the presence of symbionts. The results revealed four GIMAP-like genes in the *E. pallida* genome, which are referred to as *Ep_GIMAPs*. Induction of apoptosis resulted in a general downregulation of *Ep_GIMAPs* in both symbiotic and aposymbiotic animals indicating these proteins may be involved in pathways that promote cell survival or inhibit apoptosis. Overall, these results increase our knowledge of the role of GIMAPs in a basal metazoan.

S5-10 POPPINGA, S*; SPECK, T; Botanic Garden, University of Freiburg, Freiburg im Breisgau, Germany; *simon.poppinga@biologie.uni-freiburg.de*
Abstraction of Slow and Fast Plant Movement Principles for the Technical Transfer into Biomimetic Motile Structures
Plants can move organs or organ parts (e.g. trap leaves, flower petals, seed capsules, roots) with a variety of actuation principles. In strong contrast to most animal motion principles, the motility in plants is achieved with the complete absence of nerves, muscles and real, i.e. localized, hinges. The motion timescales and modes of deformation at work are very diverse and have recently become a source of inspiration for the development of bioinspired compliant mechanisms, which are of great interest for various fields, e.g. micro-electromechanics, microfluidics, soft robotics, medical applications and architecture. We concisely summarize the procedures in such biomimetic approaches with the help of several examples from our own research and development projects. The work processes presented include basic biomechanical and functional-morphological investigations of fast and slow plant movements, the abstraction of working principles, simulations and the transfer into novel materials systems and products. A focus is laid on systems, which are directly triggered and powered by changes of environmental conditions (e.g. temperature, humidity). With the help of such autonomous and self-sufficient actuators, reduced electrical consumption and maintenance are envisaged, which are important aspects for future technologies.

42-3 POS, KM*; KOLMANN, MA; GAO, T; HERNANDEZ, LP; GIDMARK, NJ; George Washington University, Washington DC, University of Chicago, Chicago, IL, Knox College, Galesburg, IL ; *kmpos@gwu.edu*

Morphological evolution within minnows exhibits decoupling of form & function during periods of climate change in North America

Independent lineages often evolve similar morphologies in response to similar functional demands; however, there are diverse clades where such convergence is underappreciated due to perceived phenotypic homogeneity. Many fishes, including leuciscids (Cypriniformes), are equipped with a secondary set of jaws (gill arch elements in the pharynx) that have become the primary site for prey processing. The shape of these pharyngeal jaws presumably relates to their function in feeding (i.e., robust teeth for crushing hard prey), and in minnows there are significant correlations between diet and anatomy. Using comparative macroevolutionary methods with a published phylogeny, we tested how pharyngeal phenotypes are shaped by evolutionary integration, phylogenetic signal, and diet. We used geometric morphometric methods to explore overall shape diversity, and measured functionally-relevant traits relating to feeding performance from micro-computed tomography scans of 165 species. Our geometric morphometric dataset provides us with a measure of shape change independent of functional connotations, whereas our linear morphometrics measure function directly. Our results suggest widespread anatomical and dietary convergence: clades largely overlap in morphospace and similar patterns of shape change correlate with shifts to similar diets. However, the overall shape of the pharyngeal jaws and their functional diversity do not always evolve in parallel through time; rather, changes in jaw shape and function can evolve independently. These instances of form-function decoupling are concomitant with periods of widespread climate change in North America and ecomorphological shifts in feeding zone (benthic to pelagic).

13-2 POWERS, MJ*; WEAVER, RJ; HEINE, KB; HILL, GE; Auburn University, University of Texas at Austin; *mjp0044@tigermail.auburn.edu*

First clutch size is a reliable proxy for reproductive success in a marine copepod

In experimental studies, researchers are often unable to track individuals through a natural lifetime and must rely on proxies of lifetime reproductive success. The number of offspring produced at first reproduction is readily measured and has been used as a proxy for lifetime reproductive output in studies using copepods, including the species *Tigriopus californicus*. However, the accuracy of such a proxy has been questioned and to date no validation of this approach to estimating lifetime reproductive success has been undertaken. In this study, we undertook such a validation of using the number of first-clutch offspring as a proxy for lifetime reproduction by observing the reproductive output of female *T. californicus* for the entirety of their reproductive life spans. We measured several life history traits including egg gestation duration, the number of offspring produced per clutch, the total number of clutches, offspring survival, offspring development, offspring size, and female lifespan. We found that the size of the first clutch was positively correlated with many of these measures of reproductive fitness, even after controlling for difference in female lifespan. Additionally, we analyzed variation in life history traits over the entire life span of *T. californicus* females and found that reproductive output generally declined, suggesting senescence in these small crustaceans.

82-6 POWERS, DR*; LAPSANSKY, AB; SHANNON, ES; TOBALSKE, BW; George Fox University, University of Montana; *dpowers@georgefox.edu*

Body-Temperature Management by Hovering and Perching Hummingbirds in Cold and Warm Temperatures

Hummingbirds generate large amounts of heat during hovering. When ambient temperatures (T_a) are cool this extra heat could be used as a source of endogenous heat to maintain body temperature. However, when T_a is warm this extra heat must be dissipated to avoid hyperthermia. Our previous work suggests that hummingbirds have difficulty dissipating heat while hovering in warm T_a likely requiring them to behaviorally thermoregulate after perching. In this study we used infrared thermography and standard video recordings to examine differences in heat retention/dissipation strategies between hovering and perching calliope hummingbirds (*Selasphorus calliope*, ~2.5 g) at 5, 22, and 32 °C. Based on earlier anecdotal observations we predicted that perching birds would rapidly radiate heat from the flight muscles after hovering. However, this was not supported by our data. Instead across all T_a values regulation of heat delivery to the bill, feet, and eye heat dissipation area (HDA) appeared key in controlling heat transfer during both hovering and perching. At 5 °C no heat was actively delivered to either the bill or feet when hovering or perching allowing for effective heat retention. At 32 °C the bill and feet appeared actively warmed with surface temperatures (T_s) sometimes >40 °C during hovering. T_s variation of the eye HDA was less than for the bill and feet but exhibited slightly higher T_s during hovering when heat transfer across general body surfaces is limited. While calliope hummingbirds can effectively cool while perching higher T_s of bill, feet, and eye HDA exhibited during hovering result in thermal gradients of 8-10 °C promoting dissipation of some of the heat produced during hovering even when T_a is warm.

2-2 POWERS, SD*; THOMPSON, LM; PARRY, D; GRAYSON, KL; AGOSTA, SJ; Virginia Commonwealth University, Clemson University, State University of New York; *powerssd3@vcu.edu*

Climate-related variation in metabolic rate across the geographic range of an invasive ectotherm

Our current understanding of how physiological traits respond to divergent climates as species expand their geographic ranges is still limited. Invasive species currently undergoing range expansion provide unique opportunities to study how physiological traits may evolve in relation to climate as populations spread into different and possibly novel climates. In our study, we quantified variation in thermal physiology along the latitudinal range of the gypsy moth (*Lymantria dispar*) in North America. Specifically, we measured resting metabolic rates (RMR) of larvae from 14 wild populations across the invasion front, which span 11.5°C of latitude. For each population, RMR was assayed at three ecologically-relevant temperatures (15°C, 25°C, and 30°C). From these data, we estimated a least square mean, temperature-corrected RMR for each population and tested for differences as a function of latitude and local climate variables. This analysis revealed a significant positive relationship between RMR and latitude and a significant negative relationship between RMR and a suite of climate variables. Further analysis using multi-model inference revealed annual min. temperature to be the most significant predictor of population-specific RMR. Overall, the patterns were consistent with predictions made by the Metabolic Cold Adaptation hypothesis, with elevated RMR in colder climates. This study demonstrates the evolutionary potential of thermal physiology to evolve rapidly in response to changing climates. However, as the gypsy moth invasion reached warmer southern climates the invasion front has retracted possibly because this evolutionary potential has reached its limits in the south.

57-4 PRADHAN, DS*; GROBER, MS; WHITE, KJ; Idaho State University, Pocatello, ID, Georgia State University, Atlanta, GA; *praddeva@isu.edu*

Onset and maintenance of male-typical parenting behavior during protogynous sex change

In species that change sex based on social cues, behavioral sex change is rapid and precedes gonadal rearrangement. The precise time course of both rapid and long-term behavioral changes could be highly variable and based largely on group dynamics. In this study, we attempted to better describe the initiation and maintenance of male-typical parenting behavior during protogynous sex change in *Lythrypnus dalli*, a bidirectional hermaphrodite. These fish live in groups consisting of a dominant male and multiple subordinate females. Male-typical behavior consists of nest defense, courtship jerk swims, and parenting displays involving fanning and rubbing behaviors regardless of egg presence in the nest. We studied these fish under four social contexts. First, in stable social groups consisting of a large male and size mis-matched females, males spent >99% time inside the nest and displayed high rates of parenting, while females spent ~38% time inside the nest, but did not parent. Second, we manipulated the male such that he was in the social group, but did not enter the nest. In this case, the dominant female entered the nest and cannibalized the eggs within the first 30 min, but concurrently displayed parenting and had elevated levels of brain 11-ketotestosterone. Third, we removed the male completely, which triggered a period of hierarchical instability, during which the most dominant female initiated aggression, territoriality, and short bouts of parenting. Fourth, in all female groups, at 5 d, transitioning fish spent ~34% of time inside the nest and exhibited lower parenting rates, while at 10 d, fish spent >70% time in the nest and similar rates of parenting compared to males from stable groups. Future studies will investigate whether similar hormonal mechanisms regulate parenting in males and during protogynous sex change.

111-2 PRAKASH, V.N*; BULL, M.S; PRAKASH, M.; Stanford University; *vprakash@stanford.edu*

Motility induced fractures reveal a ductile to brittle crossover in the epithelial tissues of Trichoplax adhaerens

Animal tissues are continuously subjected to dynamic force loading while they crawl, walk, run or swim. While epithelial tissues provide an important barrier function in animals, they are subjected to extreme strains during everyday activities such as breathing and feeding. However, failure or inability to withstand to these extreme strains can result in epithelial fractures, and associated diseases. Understanding tissue mechanics and adaptive response in dynamic force landscapes remains an important frontier. Motivated by understanding tissue properties at the limits of their integrity, here we carry out a multi-modal study of a simple yet highly dynamic organism, the *Trichoplax adhaerens*. We report the discovery of abrupt, bulk epithelial tissue fractures induced by the organism's own motility. Coupled with rapid healing, this discovery accounts for dramatic shape changes and physiological asexual division in this early-divergent metazoan. We generalize our understanding of this phenomena by codifying it in a heuristic model focusing on the debonding/bonding criterion in a soft-active-living material. Using a suite of quantitative experimental and numerical techniques, we demonstrate a force-driven ductile to brittle material transition governing the morpho-dynamics of tissues pushed to the edge of rupture.

49-4 PRICE, ER*; JARA, RF; University of North Texas; *edwin.price@unt.edu*

A 'Dispersal Syndrome' Approach for Relating High Paracellular Absorption in Birds and Bats to Plant Ecology

Birds and bats rely heavily on paracellular nutrient absorption, unlike non-flying mammals, which rely principally on transporter-mediated transcellular absorption. This characteristic should make birds and bats less susceptible to the physiological effects of naturally occurring plant toxins that inhibit intestinal glucose transporters, such as SGLT1. Previously, E.R.P and colleagues proposed that this could allow plants to favor flying seed dispersers, thus encouraging long-distance dispersal. While this is difficult to test, a more tractable approach takes advantage of the 'dispersal syndrome' concept. Historically, a mammal/bird dichotomy has been suggested for dispersal syndromes in forest ecosystems. Here we propose a flyer/nonflyer dichotomy, thus grouping bats with birds. Further, we propose that plant secondary metabolites be included as a key trait in this syndrome.

32-4 PRINZING, TS*; BIGMAN, BS; SKELTON, Z; WEGNER, NC; DULVY, NK; Simon Fraser University, Burnaby BC, Scripps Institution of Oceanography, La Jolla CA, NOAA Southwest Fisheries Science, Center La Jolla CA, Simon Fraser University Burnaby, BC; *tprinzin@sfu.ca*

Paired Estimates of Metabolic Rate and Gill Surface Area in the Horn Shark (Heterodontus francisci)

Metabolic rate underpins life history traits such as reproduction and growth rate and in turn, the maximum population growth rate of a species. However, our understanding of the metabolic basis for life histories and population dynamics is hindered by the challenge of using laboratory respirometers to estimate metabolic rate, resulting in relatively few estimates of metabolic rate for larger, aquatic organisms. An alternate approach is to seek morphological proxies for metabolic rate, such as respiratory surface area. Metabolic rate is highly correlated with respiratory surface area, yet there are exceedingly few paired estimates to allow a direct comparison of these traits in the same individuals. Here, we estimated resting and maximum metabolic rates in addition to gill surface area in a coastal elasmobranch, the Horn Shark (*Heterodontus francisci*), across a broad size range. We found that resting metabolic rate and body mass scaled with a slope of one, while the slope of maximum metabolic rate and body mass was significantly greater than one. These results are consistent with those of similar species and suggest that the aerobic capacity of this species increases through ontogeny. We will also discuss the scaling of gill surface area with body mass and with resting and maximum metabolic rates. By estimating these traits together in the same individuals, our work elucidates the allometric scaling of gill surface area in relation to both resting and maximum metabolic rates while minimizing the confounding factor of intra-individual variation. Overall, the results of this study may be used to inform life histories and conservation efforts of vulnerable, data-poor species.

71-2 PROVINI, P; Centre for Research and Interdisciplinarity, Paris, France; *pauline.provini@cri-paris.org*

Birdsong for human(e) voices: Building efficient voice prostheses inspired from bird vocal system

Our voice is used to communicate but also defines our identity. Thus, a voice alteration can cause emotional and social issues. Patients suffering from an advanced stage of laryngeal cancer often have to undergo a total surgical removal of the larynx, which is the human voice source. To recover the ability to speak, a prosthesis, mimicking the vocal folds, is usually placed between the trachea and the oesophagus. The exhaled air crosses a vibrating element and produces a substitute voice. Unfortunately, the created voice is of poor quality: it is weak, with a low pitch and sounds mechanical. In addition, the limited lifetime of the devices, due to biofilm coming from mucus/material interactions, forces a frequent device replacement. To date, there is no voice prosthesis lasting more than 3 months and able to reconstruct a natural-sounding human voice. In this context, birds should attract attention. First, their vocal repertoire is incredibly diverse, with pitch spanning from 100 to 12 000 Hz, compared to only 85 to 255 Hz in human speech. Moreover, their unique vocal organ, the syrinx, produces sounds from the vibration of membranes, located in the wall of the syrinx, meaning that the air is flowing through the vocal tract without crossing any structures, unlike in mammals. By quantifying the 3D motions of the vocal system during sound production and modulation, we will build a predictive aero-acoustic model we can use to ask "what if" questions and understand cause-effect relationships between shape, motions, and produced sounds. Our interdisciplinary approach, integrating biology, physics and computer science will provide fundamental principles we want to apply to the design of a new generation of vocal prostheses that will produce voices that are more humane.

138-3 PUTLAND, RL*; MACKIEWICZ, AG; ROGERS, LS; MENSINGER, AF; University of Minnesota Duluth, University of North Carolina, Chapel Hill, University of Washington; *rputland@d.umn.edu*

Effect of anthropogenic sound on the communication space of the oyster toadfish, Opsanus tau

Many animals rely on sound for important cues about their environment, yet there is an increasing awareness that anthropogenic sound may be threatening the ability of individuals to communicate. For the oyster toadfish, *Opsanus tau*, vocal communication and sound detection are critical for reproductive success, however little is known about how they may respond to changes in their acoustic environment. Passive acoustic monitoring was conducted in a small harbour (Eel Pond, MA, USA) to pinpoint the location of male oyster toadfish producing mating vocalizations, termed boatwhistles, to attract females. Significantly less vocalizations were detected following exposure to continuous vessel sound (100 – 12,000 Hz, source level 130 dB re 1 µPa), suggesting individuals changed their vocal behavior in response to anthropogenic activity. To investigate the physiological effects of anthropogenic sound, toadfish auditory sensitivity was also tested in laboratory experiments using the auditory evoked potential technique, before and after exposure to 1 hour of vessel sound. Auditory sensitivity (100 – 500 Hz) significantly decreased following exposure to vessel sound and did not return to baseline levels until 6 days after. This study highlights that vessel sound influences both the behaviour and physiology of aquatic life. The masking effect of overlapping frequencies from continuous vessel sound, and temporary threshold shifts in auditory sensitivity, is suggested to reduce communication space: the ability to detect, perceive and response to conspecifics and ultimately lead to a failure in mate attraction and detection.

42-6 QUINN, BL*; MORALES, AE; SIMMONS, NB; Temple University, American Museum of Natural History; *brooke.quinn@temple.edu*

Predicting Foraging Strategies from Morphological Traits in Myotis

The mouse-eared bats (*Myotis*) are found on every continent except Antarctica and comprise three primary ecomorphs with different feeding strategies (i.e. aerial hawking, gleaning, and trawling for aquatic prey). Despite striking morphological similarities within ecomorphs, molecular phylogenies have shown that these groups are not monophyletic. In this study, we use phylogenetic comparative methods, machine learning tools and morphological data to understand which traits are linked to the convergent phenotypes and foraging strategies of *Myotis*. We evaluated 15 traits hypothesized to be of significance for predicting foraging strategies in an analysis of over 300 specimens representing 54 species from 6 continents. No phylogenetic signal was found for any of the traits, with each trait displaying a low K value and lacking statistical significance, suggesting that similarities among different species in these traits is due to convergence rather than shared ancestry. Convergence analyses using comparative methods revealed significant changes in the mean values for each trait at particular nodes of our tree, and detected a lower number of regimes than shifts for each trait, which together are indicative of convergent evolution. A machine-learning analysis to predict feeding type resulted in an accuracy rate equal to or greater than 75%. The three most important traits for prediction of foraging strategy in *Myotis* are ear length, tibia length, and foot length. Ear length may play a role in the ability of bats to hear prey-generated sounds, and tibia and foot length may play a role in prey capture using the uropatagium and feet.

S10-8 RADER, JA*; MOHAMMADI, S; HEDRICK, TL; WALDROP, LD; University of North Carolina, Chapel Hill, NC, Chapman University, Orange, CA; *jrader@live.unc.edu*

Modeling diversification and constraint in avian wing morphology

Morphological evolution, especially in the context of adaptive radiation, can be thought of as a process of niche filling wherein species diversify in their ecological habits to exploit the available resources. Interspecific competition is avoided, generally, via phenotypic divergence that facilitates specialization on subsets of the total available resource set. Classic studies of adaptive divergence have focused on morphological characteristics, linking form to function, and function to evolution. While these studies have provided valuable insight into the processes that drive and shape morphological evolution, they do little to explain the processes that may constrain it. This is, in part, because it is difficult to assess the total available niche space that species could theoretically diversify to fill. Without this critical piece, it is difficult to ascertain where within this theoretical space species are competitively excluded, where they are constrained by their ancestry, or where their evolutionary trajectory has led them to the edge of theoretical parameter space. Furthermore, the biomechanical performance landscape conferred by morphological attributes may be a complex assemblage of peaks of high performance amid less advantageous valleys. We used computational fluid dynamics to model lift to drag ratio as a measure of flight performance in a morphological parameter space for bird wings composed of three axes: aspect ratio, camber, and Reynolds number. We then used a large dataset of 3-dimensionally scanned wings from 101 species of birds to assess what proportion of the theoretical performance they have diversified into, and what regions and proportion of that space they occupy.

119-5 RAGLAND, GJ*; DOWLE, EJ; POWELL, THQ; FEDER, JL; HAHN, DA; University of Colorado, Denver, University of Otago, State University of New York, Binghamton, University of Notre Dame, University of Florida; *gregory.ragland@ucdenver.edu*

Genome-wide variation and transcriptional changes in diverse developmental processes underly the rapid evolution of seasonality in a temperate fly

Seasonal timing, or phenology, is a critical adaptation that has long served as a model for evolution across spatial, climatic gradients and for rapid evolution in response to changing environments. In animals, however, we have a limited understanding of the genetic variation that facilitates this evolutionary flexibility. The most well-developed studies focus on photoperiodically-cued phenology, whereas there is very little known about the genetic and physiological basis for phenology that is primarily determined by environmental temperature. We used full genome resequencing in combination with a comparative, time series analysis of transcription during the course of diapause (winter dormancy) to explore how a recently derived population of the apple maggot fly, *Rhagoletis pomonella*, has evolved earlier phenology compared to an ancestral population with relatively later phenology. The results robustly support a polygenic model for phenology, wherein many genetic variants affecting diverse developmental processes lead to a more rapid progression through diapause in the recently evolved population. We link these comparative results with observations from *Drosophila melanogaster* to further suggest that diapause represents an extreme slowing, but not arrest of development, and that the same variants that may affect the duration of any developmental process also govern the duration of diapause.

47-5 RAGSDALE, A.K*; DUTOIT, L; BESSON, A.A; KING, T; GEMMELL, N.J; HORE, T; JOHNSON, S.L; University of Otago, NZ, University of Alberta, Canada; *alexandria95ragsdale@gmail.com*

Paternal hypoxia exposure primes offspring for increased hypoxia resistance

Increasingly, studies are revealing that the environmental challenges experienced by an organism can not only have multiple effects on an individual level, but that these challenges may also impact unexposed offspring. Hypoxia is a physiological challenge that many aquatic organisms encounter in their environment, resulting in in numerous physiological, phenotypic, and epigenetic changes in aquatic organisms. In this study, we use zebrafish (*Danio rerio*) as a model to investigate how paternal hypoxia experience impacts subsequent progeny. Males were exposed to moderate hypoxia (11-13 kPA) for 2 weeks, bred to create an F1 generation, and progeny underwent an acute hypoxia (0-1 kPA) tolerance assay. Using time to loss of equilibrium as a measure of hypoxia resistance, we show that paternal exposure to hypoxia endow offspring with a greater tolerance to acute hypoxia, compared to offspring of unexposed males. In addition to phenotypic alternations, we also investigated changes in gene expression in offspring. We conducted RNA-Seq on whole fry and detected 89 differentially expressed genes, including two hemoglobin genes and a selenoprotein that are significantly upregulated by more than 4-fold in hypoxia offspring. Paternal exposures to physiological challenges are thus able to impact the phenotype and gene expression of their unexposed progeny. Future research will investigate whether changes in DNA methylation underpin the observed changes in phenotype and gene expression.

86-1 RAHMAN, MS*; RAHMAN, MS; University of Texas Rio Grande Valley; *mdsadequr.rahman01@utrgv.edu*

Effects of Heat Exposure on Antioxidant Expression and Redox Status in the American Oyster: A Laboratory Study

Increasing atmospheric temperatures significantly influence the physiological functions in aquatic organisms, particularly the marine invertebrates which are extremely susceptible to elevated temperature. In this study, we observed the effect of elevated temperatures (16, 22, 26, and 30°C for 1-week exposure) on the morphology as well as on the prooxidant and antioxidant homeostasis in gills and digestive glands of American oyster, *Crassostrea virginica*. Immunohistochemical analysis was performed to observe the expression of heat shock protein 70 (HSP70, an indicator of heat stress), dinitrophenyl (DNP, a biomarker of reactive oxygen species, ROS), nitrotyrosine protein (NTP, an indicator of reactive nitrogen species, RNS), catalase (CAT, an antioxidant), and superoxide dismutase (SOD, an antioxidant) in gills and digestive glands of oysters. Histological analysis showed an increase in mucus secretion, a common response to different stressors, with increasing temperature in both tissues along with the enlargement of lumens of digestive glands. Immunohistochemical analysis showed a significant increase of HSP70, DNP, and NTP protein expressions with elevated water temperature from 16 to 30°C, indicating rising temperatures induce thermal stress which leads to increased oxidative stress as well as nitrosative stress. Interestingly, the expression of CAT and SOD increased from 16 to 26°C in oyster tissues, however, a significant drop in expression of CAT and SOD was observed at 30°C which indicates that oyster tissues become defenseless against the attack of ROS and RNS at high temperature. Collectively, we conclude that elevated seawater temperature induces oxidative and nitrosative stresses which may trigger cellular apoptosis in American oyster.

39-8 RAJA, SV*; SANE, SP; National Centre for Biological Sciences, Tata Institute of Fundamental Research; *sreekrishnavr@ncbs.res.in*

Collective movements of mound-building termites

Social insects maintain order despite large and varying number of group members and changing environmental conditions. For instance, in termite mounds, the numbers of individuals can fluctuate a great deal, as do the ambient conditions under which they operate in their underground nests. Previously, we showed that when a mound surface is breached, the termites (*Odontotermes obesus*) can repair the breach within a short duration through their collective actions. This observation suggested that there is an increased traffic towards the breach. How well-ordered is this collective movement within the nests? In general, how do termites modulate their traffic towards a breach in the mound? To address these questions, we developed a laboratory assay to study collective movement of termites. Termites were introduced in a circular arena, and their milling behaviour monitored while altering the ambient conditions within the arena. Our experiments show that whereas mechanosensory cues are required to initiate the milling behaviour, after some duration the termites lay pheromone trails that provide chemical cues to help maintain other members on a trail. This behaviour is density-dependent such that greater number of termites within the arena means that behaviour is initiated earlier. We have also conducted experiments to monitor such movements in natural conditions by introducing a camera deep within the mound through a breach. We observed termites moving in small groups towards the breach through tunnels, and forming transient lanes as they moved towards the breach, and their number increased with time. Together, these results show that termite movement in both laboratory and nature is highly ordered, and maintained by mechanical and chemical cues.

93-3 RAMENOFSKY, M*; PRADHAN, D; AUSTIN, SH; SOMA, K; SCHLINGER, B; University of California Davis, Idaho State University, Pocatello, Oregon State University, Corvalis, University of British Colulmbia, Vancouver, University of California, Los Angeles; *mramenofs@ucdavis.edu*

Phenotypic Flexibility of Glucocorticoid Signaling in Skeletal Muscles of White-crowned Sparrows Preparing to Migrate

Glucocorticoids (GC) are associated with responses to stress and also energy metabolism, tissue remodeling and homeostasis. At low circulating levels GC bind high-affinity mineralocorticoid receptors (MR) and affect anabolic pathways including tissue repair and homeostasis. At elevated levels, they bind to GC receptors (GR) activating catabolic pathways. Avian migrants express phenotypic flexibility by seasonally modifying anatomy, physiology and behavior to accommodate energetic demands of each stage. We hypothesized that GC signaling may contribute to the phenotypic flexibility in the pectoralis (flight) and gastrocnemius (leg) muscles in sparrows on the wintering grounds at three distinct stages leading up to migratory departure in spring: winter, pre-nuptial molt, and pre-departure. CORT was detected in plasma and in both muscles but CORT signaling differed across muscles and stages. Both plasma and pectoralis CORT were elevated at pre-departure ($p<0.05$). Expression of 11 -hydroxysteroid dehydrogenase (11 -HSD) Type 2 (inactivates CORT) increased in the pectoralis at pre-departure ($p<0.05$), whereas, 11 -HSD Type 1 (regenerates CORT) did not change. Neither isoform was detected in the gastrocnemius. Expression of MR only was elevated in pectoralis at pre-departure ($p<0.05$). These data suggest that anabolic functions predominate in the pectoralis only while catabolic activity is undetected in either muscle at pre-departure. Thus, we find evidence for potential pathways by which GC signaling may function to regulate the phenotypic flexibility expressed by birds anticipating migratory departure.

100-4 RAMIREZ, RW*; RIDDELL, EA; WOLF, BO; University of New Mexico, University of California, Berkeley; *ricram@unm.edu*

Seasonal and geographical variation in thermoregulatory performance of Cricetid rodents in the Mojave desert

Desert environments challenge animals by exposing them to extreme heat while simultaneously providing little water. When exposed to environmental temperatures above body temperature, rodents rely on evaporative cooling as means for dissipating excess heat. However, the high water requirements associated with evaporative cooling produce a physiological trade-off between conserving water to maintain hydration and using water to cool evaporatively. For many desert rodents, we lack a complete understanding of the thermoregulatory strategies in the heat, especially the simultaneous responses in evaporative cooling, metabolic heat production, and body temperature variation. We examined seasonal and geographic variation in thermoregulatory strategies of four species of Cricetid rodents to understand physiological response to local climatic variables. We used flow-through respirometry to measure evaporative water loss, metabolic heat production, and body temperature as a function of ambient temperature. Our research focused on *Neotoma albigula, N. lepida, Peromyscus eremicus*, and *P. crintus* at four sites with elevations ranging from 300-1600m in the Mojave Desert. We found interspecific differences in the use of hyperthermia as a strategy to conserve water, and in general, thermoregulatory strategies appeared to focus on water conservation during the summer during periods of extreme heat and water scarcity. Moreover, thermoregulatory strategies also depended on recent exposure to local temperature, humidity, and precipitation patterns. Understanding physiological responses to local climate variability will improve predictions for forecasting the physiological impact of climate change.

7-8 RANGEL, RE*; SORTE, CJB; University of California Irvine, Irvine, CA; *racine.rangel@gmail.com*

Staying local: small-scale environmental history influences the metabolic response of marine invertebrates to increased temperature

As ocean temperatures steadily rise, marine species will be exposed to temperatures that are increasingly over their physiological optima. In order to anticipate species' responses to rising temperatures, we need to know the relationship between metabolic rate and thermal history, which itself may vary at small-scales in space and time. We measured metabolic rates of hermit crabs (*Pagurus hirsutiusculus*) and mussels (*Mytilus trossulus*) and evaluated the relationship between thermal sensitivity and thermal history. Organisms were collected from 24 tide pools in Sitka, Alaska in which we also recorded temperature every five minutes for three months prior to metabolic rate assays. Using respirometry, we estimated resting mass-specific oxygen consumption (MO_2) at three different temperatures (10°C, 18°C, and 26°C) for one hermit crab and one mussel from each tide pool at three seasonal time points. We tested for linear relationships between thermal sensitivity (individual MO_2 slopes) and the following environmental parameters: average, variance, maximum, minimum, and range of pool temperatures. For both species, there were relationships between thermal sensitivity and thermal history; however, the direction of the relationships and most important thermal parameters differed between species and seasons. These findings show that thermal environmental history at small scales strongly influences metabolic response to temperature increase within populations and in ways that differ notably between species and seasons.

126-8 REED, AJ*; WOFFORD, SJ; Behavioral and Sensory Ecology Laboratory, Dept. of Biology, Jacksonville State University; *areed10@stu.jsu.edu*

Turn It Down! The Effects of Acoustic Stimuli on Contest Dynamics in Crayfish

Agonistic interactions are ubiquitous across animals and these behaviors can establish dominance hierarchies that play a role in mating and resource distribution. Stressful environments can have effects on this behavior, influencing these hierarchies. For example, Anthropogenic noise has been shown to negatively influence social behaviors in several aquatic and terrestrial organisms. Crayfish, like many other aquatic crustaceans, rely heavily on chemical stimuli to find food, mates, and to interact with conspecifics. However, limited studies have shown that some aquatic decapod crustaceans produce and react to acoustic stimuli. The extent to which crayfish can detect and react to acoustic stimuli is still largely unknown. The purpose of this study was to investigate the potential impacts of non-natural noise, in the form of introduced vibrations, influenced agonistic behaviors in crayfish. Crayfish were socially isolated from opponents for one week before being paired together for a contest. Control animals were isolated without vibrational stimuli for this period, while noise treated animals were isolated in aquaria connected to a vibrational stimulus. Dyadic contests were recorded and analyzed based on the length of the first agonistic bout as well as the maximum behavioral intensity reached during the first bout. Initial findings have not shown significant differences in contest duration or maximum intensity between control and treatment animals. These findings imply that a sound stimulus of this frequency does not play a significant role in contest dynamics, or this frequency is not a physiological or behavioral stressor.

83-5 REESE, SJ*; MILLION, KM; PROFFITT, MR; Howard University, Indiana University; *sierrajreese@gmail.com*
Response to Visual and Olfactory Stimuli in Darters (Etheostoma) during Mate Choice Trials
Sensory integration (the coordination of multiple sensory systems to carry out a behavior) has rarely been evaluated in the context of female mate choice in fishes. Understanding the sensory modalities of mate choice can provide critical insights into mechanisms of sexual selection within a group. Darters are a common model system in studies of behavior, including two species endemic to North America, *Etheostoma caeruleum* (Rainbow Darters) and *Etheostoma flabellare* (Fantail Darters). The goal of this study was to use three experiments to test female responses to olfactory and visual mate choice-related stimuli in both Darter species: In each experiment, female choice was assessed by how much time she spent in either of two preference zones. First, females were presented with an olfactory stimulus from live males of the same species. Second, females were introduced to a visual stimulus that consists of painted male models. The third phase combined both the olfactory and visual stimuli. Our results showed that the female darters of both species needed both the visual and olfactory stimulus to interpret the information effectively. Rainbow Darters were repelled by the olfactory stimulus alone in phase one, while Fantail Darters showed no response. In phase two, both species were somewhat more responsive to the visual stimulus. Finally, in phase three, females demonstrated a stronger response to the olfactory and visual cues combined, although the female Fantail Darters were still less responsive to the stimuli overall. These results suggest that female Darters may be using olfactory cues to make their decisions, but the olfactory cues need to be paired with a visual stimulus in order for them to interpret the olfactory information effectively.

123-2 REGAN, MC*; ASHLEY-ROSS, MA; Wake Forest University; *regamc13@wfu.edu*
Morphological Scaling and Ontogeny of Shark Caudal Fins
Sharks are critical to ocean ecosystems and have been studied in many ecological and biomechanical capacities. One area of study that is relatively lacking is analysis of caudal fin shape with respect to ecological changes throughout ontogeny. Caudal fins are the sharks' main propulsion structures and as such can dictate a certain amount of their behavior such as what prey they go after, what habitats they occupy, and how they grow over time. Many sharks begin in a nursery environment, such as mangroves, which can protect against predation before becoming large enough to occupy their adult habitats. This study aimed to focus on how the caudal fin may be changing as the shark grows both within a species and amongst a variety of species. After analyzing nine species across five orders it was found that certain linear tail measurements are changing allometrically but many are growing isometrically. Those that are allometric may be adjusting their caudal lobe ratios to better fit their adult environments after leaving their juvenile nursery habitats. Further studies should focus on quantifying the fluid dynamics behind these shape changes to better understand the role the caudal fin is playing in their lifespan.

56-6 REICH, HG*; RODRIGUEZ, IB; TRIPP, SE; WARNER, ME; KEMP, DW; HO, TY; LAJEUNESSE, TC; Penn State Univeristy, University of the Philippenes, Penn State University, University of Delaware, University of Alabama at Birmingham, Academia Sinica, Penn State University; *hgreich16@gmail.com*
Symbiotic dinoflagellates pump iron (and other trace metals) to beat the heat
Trace metals, especially iron, are required for virtually all biochemical and metabolic processes. Coral thermal tolerance is attributed mostly to individuals pre-conditioned to thermal stress, access to greater nutrient reserves (from heterotrophy), and the photo-physiological capabilities of their resident algal symbiont. However, the underlying role of trace metals in these processes remains largely unknown due to several technical challenges when applying trace metal clean methods. With continued ocean warming, a possible decrease in iron availability raises questions about how this may affect reef coral physiology. To examine the importance of trace metals for Symbiodiniaceae physiology and metallome (elemental content), cultures were exposed to various (ecologically relevant) iron concentrations and temperatures. Additionally, metallomes of Symbiodiniaceae (in hospite) were compared between reefs with different thermal regimes. Sufficient iron concentrations (>50 pM Fe'), were needed by cultured symbionts to cope with heat stress. Moreover, one species that actively acquired more iron (and other metals) during thermal stress, exhibited greater thermal tolerance and cell growth. Furthermore, symbiotic algae extracted from corals living in high temperature environments exhibit different elemental compositions relative to conspecifics living in cooler habitats. Such differences in elemental composition among heat tolerant corals may correspond to increased enzymatic activity or other protective processes. The scope and significance of trace metals to biochemical pathways that support coral-algal symbioses under normal and adverse conditions deserves more attention.

131-6 REICHERT, MS*; KULAHCI, IG; DAVIDSON, GL; QUINN, JL; Oklahoma State University, University College Cork, Cambridge University; *michael.reichert@okstate.edu*
Scrounging Versus Learning Strategies in Foraging Songbirds
Cognition is important for foraging because individuals can learn and remember profitable sources of food. However, cognition is not the only way to find food. Particularly in group living species, some individuals may successfully forage by scrounging from others. Both tactics may be effective, but there are likely trade-offs in their expression because both cognitive ability and competitive scrounging entail high developmental costs. However, few studies have investigated individual variation in cognitive ability and scrounging, and trade-offs between these traits, in wild populations. We measured individual learning speeds and scrounging rates in large mixed-species flocks of 3 songbird species: great tits, blue tits and marsh tits. We used arrays of bird feeders that were programmed so that each individual was only able to access food in one of the five feeders at an array. We measured the speed to learn to use the rewarded feeder as well as rates of scrounging at the non-rewarded feeders. Individuals that scrounged more often were slower to learn the task, suggesting a trade-off between cognition and scrounging. Blue tits scrounged more than the other species, perhaps because they were less competitive in accessing their own rewarded feeder. Nevertheless, scrounging behavior was not repeatable. In reversal learning experiments, birds tended to scrounge more at previously rewarding feeders, but did not preferentially scrounge from other birds that had also been assigned to that feeder. Our results reveal a fundamental trade-off between foraging strategies based on learning and scrounging, but the drivers of individual variation in these traits are complex and additional experimental studies are needed to determine how these strategies are related.

137-6 REISENFELD, K*; MCELROY, E; ROOSENBURG, W; The College of Charleston , Ohio University ; *reisenfeldk@g.cofc.edu*
Functional Ecomorphology in the Diamondback Terrapin (Malaclemys terrapin); the Effect of Head-starting on Morphology and Bite Force
Head-starting describes the captive rearing and care of animals through their juvenile life stage, followed by release into their native habitats. The goal of head-starting programs is to avoid high mortality of hatchlings and thus increase overall population size. *Malaclemys terrapin* populations are declining throughout their range due to increased nest predation, road mortality, habitat loss, commercial harvest for food, and bycatch in crab pots (Dorcas et al., 2007). A *M. terrapin* head-starting program in Chesapeake Bay suggest that survival of accelerated animals is lower than wild animals (Jenkins, 2018). Morphological performance may effect an individual's ability to gain resources (Elnitsky and Claussen, 2006; Herrel et al., 2002), and therefore reduce survivorship. Bite force is one morphological performance measurement that is affected by diet and corresponding head and body morphometries (Herrel et al., 2018; Marshall et al., 2012). Head-started *M. terrapin* are fed a soft pellet diet, which may yield individuals with reduced bite force that are unable to forage on the hard-shelled prey accessible to them upon release. Bite force, head, and body morphometries were collected from *M. terrapin* across all ages on Poplar Island, MD. Bite forces were correlated to body and head size to determine their effect across ontogeny. The force needed to crush prey items found in the Chesapeake Bay was obtained to determine if head-started terrapins are able to forage post-release. We evaluate if bite force and morphometries are different in head-started M. terrapin and therefore explain the reduced survivorship of released individuals.

52-5 RENNOLDS, CW*; BELY, AE; University of Maryland, College Park, MD; *rennolds@umd.edu*
Injury improves short-term environmental stress tolerance in a freshwater annelid
Both the loss of tissue and the regeneration of tissue are expected to impose considerable physiological costs on animals. Although injury is common in nature and regeneration is widespread among animals, the impacts of injury and regeneration on physiological performance remain poorly studied in many animal groups, especially aquatic invertebrates. Furthermore, distinguishing the costs of injury from those of regeneration specifically is challenging, and studies that attempt to distinguish these are rare. Working with the freshwater annelid *Pristina leidyi*, we tested the effects of traumatic tissue loss and regeneration on performance, focusing specifically on environmental stress tolerance. Amputation injury either decreased or did not affect acute cold tolerance, depending on the location of the injury. However, contrary to our expectations, amputation injury actually improved tolerance to both acute heat stress and salinity stress. Regeneration of tissue only significantly reduced heat tolerance, an effect that was also dependent upon injury location. Based on our finding that injury improves tolerance to multiple distinct stressors, we hypothesize that injury induces a generalized cellular stress response that can prime animals to better manage subsequent homeostatic challenges. RNA-seq and microrespirometry experiments are ongoing to test this hypothesis and further explore the physiological responses to injury and regeneration.

98-6 RESH, CA*; BENESH, KC; MAHON, AR; Central Michigan University; *carlee.resh@gmail.com*
Sourcing Invaders: A Northern Snakehead Story
The introduction and subsequent expansion of the Northern snakehead (*Channa argus*) in North American waters is one of many problematic biological invasions in the United States. This harmful aquatic invasive species is a predatory freshwater fish native to Asia that has established itself in multiple water basins in the eastern United States, as well as an expanding range in the Midwest. Previously, we assessed the population structure and estimated long-term effective population sizes of the populations present in the United States. However, the source of introduction for these fish remains unknown. In this work, we aim to determine the source of the North American introductions. To accomplish this, we used whole genome scans (2b-RAD genomic sequencing) to analyze single nucleotide polymorphisms (SNPs) that allow us to screen the genomes of captured fish from both United States waters and from a number of sites in their native range. Using this cost-effective approach, we recovered 2,632 single-nucleotide polymorphism (SNP) loci from genomic DNA extracted from 194 fish: 164 fish sampled from the eastern United States and Arkansas, and 30 fish sampled from three regions of the Yangtzee River basin in China (n=10 per basin). Preliminary analyses directly link a fish captured in the Upper Hudson River basin to two Lakes that are part of the Yangtzee River basin in China. This valuable information has the potential to result in more effective management of this harmful invasive species. Furthermore, additional sampling from the native range could help to determine the source(s) of introduction for the other fish in the eastern United States and Arkansas, and therefore aid management in preventing future introductions into United States waterways.

38-1 RICE, N*; JEONG, S; NISHIKAWA, K; Northern Arizona University; *kiisa.nishikawa@nau.edu*
How do Muscle Length and Activation Interact to Determine Muscle Force Production?
Previous studies demonstrated dissociation of muscle activation and force during in vivo treadmill running over obstacles in the lateral gastrocnemius (LG) muscles of guinea fowl. There was a long (90-150 ms) and variable delay between EMG onset and force onset, and the correlation between peak EMG and peak force amplitude ($r^2 = 0.30$) was small compared to the correlation between muscle length at foot contact and peak force amplitude ($r^2 = 0.63$). To further demonstrate decoupling between force and activation, we used ex vivo extensor digitorum longus muscles (EDL) of mice as an "avatar" for the in vivo guinea fowl LG. Instead of sinusoidal or triangular length inputs typically used in workloop experiments, we used length records from the guinea fowl LG recorded in vivo using sonomicrometry as inputs for ex vivo workloop experiments. Muscles were stimulated submaximally with similar onset and duration to in vivo guinea fowl muscles. Work loops recorded ex vivo in EDL strongly resembled those from the guinea fowl LG during in vivo treadmill running. Both ex vivo EDL and in vivo LG workloops deviate substantially in shape from traditional ex vivo workloop experiments, demonstrating the importance of small high-frequency perturbations to muscle force production. A titin-based muscle model accurately predicted muscle force for both in vivo and ex vivo muscles ($r^2 > 0.80$). While these studies demonstrate that muscle length and velocity regulate muscle force production, the results suggest that neither the isometric force-length relationship nor the isotonic force-velocity relationship describes their roles during in vivo force production.

89-2 RICHARDSON, C.S*; LOONEY, C.; INESON, K.; FLETCHER, J.; SILLAH, A.; EISEMAN, H.; Lesley University, Northeastern University, University of New Hampshire, University of Massachusetts-Amherst, Tufts University; *crichard@bu.edu*

Understanding the Role of Intrinsic Physiological Factors in the Population Recovery of Myotis lucifugus (little brown myotis) from White-nose Syndrome

Since 2006, white-nose syndrome (WNS) has had a devastating impact on populations of *Myotis lucifugus* (little brown myotis) in North America. However, some remnant populations are starting to recover. As soon as they emerge from hibernation, many bats continue to fight the *Pseudogymnoascus destructans* (*Pd*) fungus infection, the cause of WNS, and then recover from the disease, which costs energy. Understanding the energetic cost of the immune response of the little brown myotis to this fungal infection is important for understanding how this important species is recovering from this disease. We examined basal metabolic rate (BMR), an important measure of energy expenditure, and bacterial killing ability of blood and white blood cell count, both important measures of immune ability in the bats. We also assessed wing damage due to the *Pd* fungus, because the extent of wing damage reflects the course of immune response and recovery by the bat to the fungus. *Pd* fungal load of the bat was assessed as well. We hypothesized that fungal activity will cause increased immune response, costing energy that would otherwise be used towards pregnancy. We examined whether population growth and recovery in some bat maternity colonies is affected by energy cost of immune response and recovery to WNS. We found the colony with the highest rate of growth did not have the highest energy use or immune response, but the differences among colonies in energy use and immune response changed with pregnancy. Additionally, contrary to our hypothesis, no significant relationship between fungal load and BMR was found.

74-4 RIDDELL, EA*; IKNAYAN, KJ; WOLF, BO; BEISSINGER, SR; University of California, Berkeley, University of New Mexico; *riddell.eric@gmail.com*

Thermoregulatory costs drive responses of mammal and bird communities to climate change in the Mojave Desert

Climate change might dramatically increase extinction risk by threatening the most basic, physiological requirements for survival. Despite the threat of overheating and dehydration, very few studies have demonstrated a physiological basis for population-level responses to climate change, especially in endotherms. Climate change has the potential to challenge endotherms by disrupting their ability to maintain a stable body temperature, a fundamental requirement for survival. We evaluated community responses to climate change in the Mojave Desert over the last century using occupancy surveys for birds and mammals. As part of the Grinnell Resurvey Project, we compared the change in occupancy from modern surveys with surveys originally conducted by Joseph Grinnell *et al.* in the early 20th century. We then explored the physiological basis of species' responses to climate change using heat flux models that estimated the climate-driven change in thermoregulatory requirements for birds and mammals. For bird communities, we found a nearly 50% reduction in biodiversity across our resurvey sites. Mammal communities however were relatively stable over the same time period. Avian declines were largely explained by the increase in thermoregulatory cooling costs over the last century, whereas mammal communities were not affected by thermoregulatory costs. Moreover, heating costs from climate change declined more in mammals compared to birds, and most mammals did not experience an increase in cooling costs. Our study demonstrates that birds and mammals have markedly different thermoregulatory experiences of climate change that influence population-level responses to recent climate change.

114-3 RIESER, JM*; LI, T-D; GOLDMAN, DI; MENDELSON III, JR; Georgia Tech, CUNY, Zoo Atlanta, Georgia Tech; *jennifer.rieser@physics.gatech.edu*

Evolutionary convergence in nanostructural adaptations in sidewinding viperid snakes

Snakes inhabit and move successfully within a wide range of environments, from sandy to rocky substrates, forest floors to tree trunks and branches, swampy areas to aquatic environments, and environmental interactions are mediated solely through skin contact. We performed atomic force microscopy (AFM) measurements to characterize the microscopic structures on the shed skins of a variety of viperid snakes that inhabit a diversity of environments. We find that, while most snakes have microfibrils oriented from head-to-tail, a few distantly-related snake species have convergently lost this structure in favor of a more isotropic morphology. We hypothesize that these microstructures affect the frictional interaction with the substrate and we use resistive force theory to model the effects of isotropic and anisotropic frictional interactions on snake locomotion. For lateral undulation, we find that an anisotropic frictional interaction in which craniad, or foreward, movement is favored over side-to-side movement is predicted to improve performance (measured in distance traveled per cycle), and that larger anisotropies yield larger displacements. In sidewinding locomotion, however, we see the opposite trend: more isotropic frictional interactions are predicted to improve performance. These predictions are consistent with our observations of microscopic structures on snake skins and provide a hypothesis for why sidewinding species of vipers share an evolutionarily convergence in morphology that is structurally distinct from other viperids examined.

103-3 RIFFELL, J*; CHAN, J; OKUBO, R; University of Washington; *jriffell@uw.edu*

Sensory biology of of mosquito-flower interactions

Mosquitoes are important vectors of disease and require sources of carbohydrates for reproduction and survival. Unlike host-related behaviors of mosquitoes, comparatively less is understood about the mechanisms involved in nectar-feeding decisions, or how this sensory information is processed in the mosquito brain. Here we show that Aedes spp. mosquitoes, including Aedes aegypti, are effective pollinators of the Platanthera obtusata orchid, and demonstrate this mutualism is mediated by the orchid's scent and the balance of excitation and inhibition in the mosquito's antennal lobe (AL). Furthermore, we show that the combination of odor and visual cues increase the ability of mosquitoes to locate the flowers. The P. obtusata orchid emits an attractive, nonanal-rich scent, whereas related Platanthera species – not visited by mosquitoes – emit scents dominated by lilac aldehyde. Calcium imaging experiments in the mosquito AL revealed that nonanal and lilac aldehyde each respectively activate the LC2 and AM2 glomerulus, and remarkably, the AM2 glomerulus is also sensitive to DEET, a mosquito repellent. Lateral inhibition between these two glomeruli corresponds to the level of attraction to the orchid scents: whereas the enriched nonanal scent of P. obtusata activates the LC2 and suppresses AM2, the high level of lilac aldehyde in the other orchid scents inverts this pattern of glomerular activity, and behavioral attraction is lost. Moreover, olfactory stimulation with the attractive orchid scent gates the attraction to visual objects, especially those with features similar to the orchid flowers. These results demonstrate the ecological importance of mosquitoes beyond operating as disease vectors and open the door towards understanding the neural basis of mosquito nectar-seeking behaviors.

23-4 RIPPE, JP*; DIXON, GB; MATZ, MV; University of Texas at Austin; *jpr6mg@gmail.com*

Genomic evidence of environmental specialization and cryptic speciation in two massive coral species on the Florida Keys Reef Tract

Broadcast-spawning coral species have wide geographic ranges, spanning strong environmental gradients, but it is unclear how much spatially varying selection these gradients actually impose. Strong divergent selection might present a considerable barrier for demographic exchange between disparate reef habitats. We investigated whether the cross-shelf gradient (nearshore - offshore - deep) is associated with spatially varying selection in two common coral species, *Montastraea cavernosa* and *Siderastrea siderea*, in the Florida Keys. We used 2bRAD to genotype 20 juveniles and 20 adults from each of the three reef zones across two cross-shelf transects to identify signatures of selection occurring within a single generation. Preliminary results from the first transect revealed unexpected results. Each species was found to be composed of four to five genetically distinct subpopulations, with gene flow between them highly reduced in 30-50% of the genome. Each species includes two sympatric populations that are only found in the deep (20 m) habitat, while the other populations are found almost exclusively on the shallower reefs (3-7 m). Here, we compare these initial findings with data from a second cross-shelf transect to investigate possible along-shore variability in the patterns environmental specialization and to establish whether cryptic genetic subdivision in these two coral species may be a general feature throughout the Florida Keys. *Siderastrea siderea* and *M. cavernosa* have emerged as two of the most ecologically successful species on the degraded Florida Keys Reef Tract, and this work offers important insight on the genomic background of divergent selection and speciation that may in part explain their broad environmental range in this ecosystem.

31-3 RIVERA, HE*; DAVIES, SW; Boston University; *hrivera@bu.edu*

What does it take to stay together? Uncovering symbiosis gene networks in a facultatively symbiotic coral

Symbioses with unicellular algae in the family Symbiodiniaceae are common across marine invertebrates. Reef-building corals offer a unique example of cellular dysfunction that leads a dysbiosis (coral bleaching) that is visible to the naked eye and occurs at an ecosystem scale. Due to their obligate symbioses, understanding the molecular underpinnings that sustain this relationship in reef-building corals is challenging, as any aposymbiotic state is inherently coupled with severe physiological stress. Here, we use the sub-tropical, facultatively symbiotic and calcifying coral *Oculina arbuscula*, to investigate gene expression differences between aposymbiotic and symbiotic host tissues from branches of the same colonies. This framework allows us to unravel the molecular networks that regulate symbiosis in the absence of a stress response. We find that many of the previously implicated pathways identified in studies using bleached corals, aposymbiotic larvae, or model systems (i.e. *Aiptasia*), are also differentially regulated between aposymbiotic and symbiotic tissues of *O. arbuscula*. We then take a comparative approach to investigate symbiosis pathways across other marine taxa. Our results point to key processes such as cell adhesion, control of cell division, and immune response, which appear necessary for the maintenance of symbiosis across organisms. Understanding the mechanisms that sustain a healthy symbiosis with Symbiodiniaceae is of urgent importance given the vulnerability of these partnerships to changing environmental conditions and their role in the continued functioning of key marine ecosystems such as coral reefs.

59-7 RIX, AS*; O'BRIEN, KM; University of Alaska Fairbanks and Institute of Arctic Biology, Fairbanks, AK; *asrix@alaska.edu*

Characterizing the Hypoxia-Inducible Factor-1 Pathway in Response to Acute Thermal Stress and Hypoxia in Antarctic Notothenioid Fishes

The master regulator of oxygen homeostasis in most metazoans is the transcription factor, hypoxia-inducible factor-1 (HIF-1), a heterodimer of HIF-1 and HIF-1 subunits. In Antarctic notothenioid fishes, HIF-1 has a polyglutamine/glutamic acid (polyQ/E) insert that varies in length with phylogeny and is longest in members of the most derived family, the Channichthyidae (icefishes), lacking hemoglobin. The impact of this insert on the function of HIF-1 is unknown. We sought to determine if the HIF-1 pathway is activated in hearts of the red-blooded notothenioid, *Notothenia coriiceps*, and the icefish, *Chaenocephalus aceratus*, in response to exposure to their critical thermal maximum (CT_{MAX}) or hypoxia of 5.0 mg L^{-1} O_2 for two hours. Additionally, *N. coriiceps* was exposed to a longer, more severe hypoxia of 2.3 mg L^{-1} O_2 for 12 hours. Levels of HIF-1 protein were quantified in nuclei using western blotting and mRNA levels of several genes regulated by HIF-1 were quantified using quantitative real-time PCR. Only severe hypoxia resulted in an increase of HIF-1 levels in *N. coriiceps*; despite this increase, mRNA levels of genes known to be regulated by HIF-1 did not increase. However, mRNA levels of lactate dehydrogenase-A decreased in *C. aceratus* exposed to mild hypoxia. Together, these results suggest that in notothenioids HIF-1 accumulates and translocates into the nucleus in response to hypoxia but may not transactivate gene expression.

105-5 ROBERTS, A*; WAINWRIGHT , P; University of California, Davis ; *asroberts@ucdavis.edu*

Anatomical basis of jaw protrusion directionality in ponyfishes (Leiognathidae)

Jaw protrusion is a key morphological innovation that enhances suction feeding performance in fishes. Though almost universally present among percomorph fishes, the biomechanical mechanism, direction, and extent of jaw protrusion varies widely. Ponyfishes (Family Leiognathidae) comprise a group of 48 deep-bodied species that inhabit the sandy shores of the Indo-West Pacific Ocean. These fishes are characterized by high jaw protrusion and unusual diversity in the direction of protrusion, with species that protrude their oral jaws in either a ventral, dorsal, or rostral orientation. While ponyfish anatomy has received some attention in the literature, no study has examined the morphological differences underlying jaw protrusion directionality. We measured craniofacial morphology from photographs of 35 cleared and staining specimens representing 21 species, spanning the range of jaw protrusion direction. We then used a functional interpretation of morphology and phylogenetic comparative methods to characterize key differences in craniofacial anatomy and determine the anatomical basis of jaw protrusion directionality within this unique family. We found that the lengths and orientations of many craniofacial elements including the ascending process, mandible, maxilla and jaw joint discriminate between the three oral jaw types. Among the many differences in anatomy, the position of the jaw joint appears to be key to the direction of jaw protrusion as its movement from a more posterior to an anterior position when looking across ventral, rostral and dorsal protruders, significantly changes the orientation of the adducted mandible from a nearly horizontal position in ventral protruders to an upright posture in dorsal protruders.

100-1 ROBERTS, KT*; WILLIAMS, CM; Univ. of California, Berkeley; *kevrob@berkeley.edu*

A gradual release of metabolic suppression during diapause termination in a montane insect

To conserve energy during winter many insects enter diapause, a dormant state in which metabolic rate is suppressed. Metabolic suppression is gradually reversed during diapause termination. Thermal conditions experienced during winter impact the degree of metabolic suppression through phenotypic plasticity. In winter, snow modifies the thermal environment by acting as an insulator that buffers from cold and variable air temperatures. The stable, constant temperatures experienced under snow may impact the degree of metabolic suppression, and the time course over which suppression is released during diapause termination. Incorporating winter metabolic plasticity in energetic models will allow us to more accurately predict how climate change will impact winter energy stress. Populations of the willow leaf beetle *Chrysomela aeneicollis* in the Sierra Nevada Mountains overwinter as adults for up to eight months of their one-year life cycle. In these environments there is highly variable interannual snowfall, which can lead to dramatically different thermal environments. Beetles were collected from the wild and overwintered under simulated stable below-snow conditions and variable exposed conditions in the laboratory. We quantified temperature-metabolic rate curves monthly from February to May through the transition of diapause to post-diapause quiescence. We found that beetles had similar thermal sensitivity and metabolic suppression regardless of winter thermal environment. As beetles transitioned out of diapause, there was no shift in thermal sensitivity, but a steady decrease in general suppression. This implies that our current models are underestimating winter energy use and that late winter warm bouts will pose greater energetic challenges for overwintering insects.

91-7 ROBINSON, KE; HOLDING, ML; CLARK, RW*; San Diego State University, Florida State University; *rclark@sdsu.edu*

Biochemical Warfare: The Coevolution of Rattlesnake Venom and Venom Resistance in Prey Species

Many animals use toxic chemicals to defend themselves or immobilize prey. The use of such compounds frequently leads to antagonistic coevolution, wherein impacted species evolve physiological resistance to the effects of these toxins and create reciprocal selection for increasingly novel toxins or delivery systems. For example, many pitviper venoms contain high levels of metalloproteinases, a class of toxins that cause hemorrhaging, tissue damage, and facilitate the spread of other toxins through the tissues of injected prey. Several different lineages of mammals (including sciurid and neotomine rodents) have evolved metalloproteinase inhibitors, proteins in the blood serum which neutralize metalloproteinases and impede the effectiveness of the venom. Individuals with high levels of inhibitors can survive envenomations that would rapidly immobilize or kill non-resistant mammals. However, there are apparently evolutionary and physiological factors that constrain snake venom resistance, because individuals of resistant species of ground squirrels and woodrats are still the primary prey items of local rattlesnakes. Venom resistance and venom chemistry can vary at the level of species, populations, and individuals. We are studying the venom of two rattlesnakes (*Crotalus oreganus* and *C. ruber*), and resistance of two mammals (*Otospermophilus beecheyi* and *Neotoma lepida*) which all co-occur at four different locations. We use fluorescent gelatinase assays to quantify metalloproteinase efficacy and resistance among individuals. We have paired venom and serum samples within and between populations to assess variation in these traits at multiple biological levels of organization.

120-6 ROBINSON, TL*; DIAZ, K; OZKAN-AYDIN, Y; WAN, KY; GOLDMAN, DI; Georgia Tech, University of Exeter; *trobinson89@gatech.edu*

Gait dynamics of a quadriflagellate robophysical model

Quadrupedal animals locomote by coordinating their limbs to generate different gaits. While limb coordination is thought to be an exclusive capability of macroscopic systems, microscopic organisms have been found to exhibit similar capabilities. Different species of micron-sized, pond dwelling algae are capable of coordinating four flagella to generate swimming gaits similar to those of quadrupeds (Wan & Goldstein, 2016). To explore microscopic locomotion control, we developed a robophysical model of quadriflagellate microorganisms which models swimming at low-Reynolds number. We focus on two distinct gaits - the pronk and the trot. The pronk gait consists of moving each flagellum simultaneously, without any phase difference between flagella. The trot gait consists of two alternating pairs of flagella each of which generates a pattern analogous to a breaststroke. The robophysical model includes four two-link flagella connected by a joint that allows each flagellum to bend, breaking drag symmetry during locomotion. The robot emulates microorganism swimming patterns, forward motion was measured at 0.30±0.09 body lengths per gait cycle (BL/cyc) using the trot gait and at 0.19±0.03 BL/cyc using the pronk gait. Results are comparable to microorganisms' performance, where using the trot gait enables a higher speed (0.39±0.18 BL/cyc) than the pronk gait (0.18±0.05 BL/cyc). The results show that hydrodynamic performance is highly sensitive to swimming gait, consistent with recent findings which suggest flagellates are capable of actively modulating flagellar phase differences for gait selection and directional navigation. However, unlike the organisms, the robot does not swim smoothly, suggesting a role of the algal cytoskeleton for gait stabilization.

126-4 ROCCO, AJ*; WOFFORD, SJ; Behavioral and Sensory Ecology Laboratory, Dept of Biology, Jacksonville State University; *arocco1@stu.jsu.edu*

Battle of the Benthic: Studying Agonistic Interactions Between a Native and Invasive Crayfish Species

Competition between individuals is often decided via agonistic interactions. When individuals encounter each other, both must assess the costs of fighting against the benefits of a potential resource gained. If both individuals' assessments determine that the cost of continued interaction is less than the benefits gained, the agonistic interaction will intensify until one individual gives up and flees. This has far-reaching ecological consequences, as losers in fights are often displaced to poorer quality food, shelter, and mate resources. Biogeographical invasion studies have shown that aggression differences between alien and native species factor into invasion success. In part, these differences mean invaders often outcompete natives for better resources. In this study, we examined the agonistic differences between a new invader to Alabama, *Faxonius virilis*, and a native crayfish, *Faxonius erichsonianus*, in dyadic interactions. Crayfish were socially isolated prior to trials. During trials, individuals were placed in a fighting arena where they acclimated for 15 minutes. Crayfish were then free to interact for 20 minutes and were video recorded from above. Interactions were scored to determine total interaction duration and the maximum behavioral intensity reached. Using this data, we can determine whether one species demonstrates significantly different levels of aggression. Preliminary trials show no significant agonistic differences across native and invasive treatments in fights between conspecifics. It is possible that success in agonistic interactions is largely irrelevant to invasion success: high fecundity and generalism may be what gives the invasive *F. virilis* its edge over Alabama's native crayfishes.

71-4 RODRIGUEZ-SALTOS, CA*; RAMSAY, G; MANEY, DL; Psychology Department, Emory University, Atlanta, Georgia, Department of Pediatrics, Emory University, Atlanta, Georgia and Marcus Autism Center, Children's Healthcare of Atlanta, Atlanta, Georgia; *bio.carodrgz@gmail.com*

An R package to measure the similarity of natural sounds via mutual information

Measuring how similar two sounds are to each other has diverse applications in biology, such as quantifying imitation in vocal learners or reconstructing patterns of sound variation across populations and species. A powerful way to measure sound similarity is to calculate the statistical dependence, or mutual information, between the power spectra of the sounds being compared. Mutual information allows the researcher to measure similarity even when spectra are not linearly correlated. Non-linear dependencies can occur, for example, when two complex sounds differ because one of them displays additional elements or some of its elements are slightly shifted in pitch relative to the other sound. In those cases, using measures that assume linearity may lead to misleadingly low values of similarity. Here, we present an R package that allows measurement of sound similarity via mutual information. The package allows the researcher to automatically compare hundreds of sounds in one batch. As an example, we present measurements of the accuracy with which several juvenile zebra finches (*Taeniopygia guttata*) imitated the vocalizations of adults. The package also allows the researcher to determine the extent to which elements from multiple sounds are represented in one composite sound. We used this feature to test the extent to which juvenile zebra finches imitated the song of one tutor versus that of a second tutor. This package is expected to increase the use of mutual information to measure similarity in natural sounds by making this method more accessible to biologists.

18-1 ROGERS, LS*; VAN WERT, JC; MENSINGER, AF; University of Minnesota Duluth, Marine Biological Laboratory; *loranzie@uw.edu*

Multimodal sensory integration of the utricle in freely swimming toadfish, Opsanus tau

Unlike the inner ear of terrestrial vertebrates, fishes have a less pronounced separation between auditory and vestibular inner ear organs. In fishes, the inner ear is composed of three paired otolithic end organs, which are multimodal and encode auditory and vestibular stimuli. To determine the effects of vestibular (movement) and auditory (pure tones or conspecific vocalizations) input, microwire electrodes were implanted using a 3D printed micromanipulator chronically into the utricular nerve of oyster toadfish, *Opsanus tau*. Fish swam freely or were moved forward at variable speeds while affixed to a sled. All utricular afferents responded to movement by increasing neural activity and remained sensitive to pure tones (125 – 200 Hz) and playbacks of conspecific boatwhistles throughout movement. This research is the first to simultaneously investigate the effects of multimodal input to the utricle during self-generated movement in free-swimming fishes.

39-6 RODRIGUEZ-SANTIAGO, M*; JORDAN, LA; HOFMANN, HA; Institute for Neuroscience, University of Texas at Austin, Max Planck Institute of Animal Behavior, University of Konstanz, Germany, Department of Integrative Biology, University of Texas at Austin; *mari.rodriguez221@gmail.com*

Social Context Affects Learning and Neural Activity Patterns in Dynamic Social Groups

During social interactions, the brain integrates current events with previous memories and predictions about future outcomes in order to respond in a context-appropriate manner. Animals are tasked with expressing context-appropriate behavior in complex social hierarchies that can undergo dynamic changes depending on group composition and individual experience. These interactions induce neuronal and physiological responses in individuals that impact their subsequent learning and decision-making. Here we examine the neurobiological correlates mediating learning in a dynamic social context in groups of the social cichlid fish, *Astatotilapia burtoni*. We first assayed the behavioral response of social groups to a simple association task with an informed individual either present or absent, and quantified how informant behavior affects the group response rate. To identify the neural substrates that mediate learning across social contexts, we analyzed the induction of the immediate-early gene *cFos* in candidate brain regions known to play a role in social decision-making and learning and memory. We find that the presence of an informant greatly facilitates group response, independent of the social status of the informant. We also find that patterns of neural activity vary according to social context rather than an individual's social status. By combining behavioral observations of social groups before and during learning with examinations of the underlying neurobiological correlates, our research provides novel insights into the neural substrates that regulate learning within dynamic social groups.

46-2 ROJO ARREOLA, L*; ROMERO , R; DIAZ DOMINGUEZ, L; GARCIA CARREñO, F; Centro de Investigaciones Biologicas del Noroeste; *lrojo@cibnor.mx*

Proteolytic profile through larvae development in Penaeus vannamei: activity and transcriptional approach

Peptidases are hydrolases that cleave peptide bonds within protein chains. In arthropods, the cleavage of specific proteins by proteases has pivotal roles in multiple physiological processes including oogenesis, immunity, nutrition, and parasitic invasion; these enzymes are also key players in larval development, well-described triggers of molting and metamorphosis, as well as fat body dissociation and tissue remodeling. *Penaeus vannamei* is a Penaeid shrimp and a key species for the aquaculture industry, but descriptions of the molecular mechanisms of many important physiological conditions including larval development are rather poor. Penaeid shrimp undergo a biphasic life cycle, meaning pelagic larvae stages followed by benthonic juvenile and adult stages. Larvae develop gradually and each stage presents morphological, physiological and ecological adaptations that fulfill its locomotive and feeding changes. In this work the proteolytic profile along the larvae development of *P. vannamei* was determined at transcript and activity levels, we quantified the gene expression of 21 annotated shrimp peptidases by qPCR. Since changes in mRNA abundance do not necessarily correlates with the corresponding mature protein products, the proteolytic activity was also assessed using fluorogenic substrates designed to be recognized by 13 specific peptidases, the data presented here will contribute to understand the proteolytic dynamics occurring during *P. vannamei* larvae development.

75-4 ROSS, SA*; RIMKUS, B; KONOW, N; BIEWENER, AA; WAKELING, JM; Simon Fraser University, University of Massachusetts Lowell, University of Massachusetts Lowell and Harvard University, Harvard University; *saross@sfu.ca*
The Effects of Muscle Internal Mass on the Contractile Behaviour of In Situ Rat Plantaris Muscle
Most of what we know about whole muscle contractile behaviour comes from measures on isolated muscle fibres or small muscles that have been extrapolated to larger sizes without considering the mechanical consequences of the additional muscle mass. Previous studies have shown that the mass of muscle tissue acts to slow the rate of force development and maximum velocity of muscle during shortening contractions and decrease the work and power per cycle during cyclic contractions. However, these studies have relied solely on model predictions and so the effects of inertial resistance due to tissue mass have not yet been confirmed by experiments on living tissue. Therefore, in this study we conducted *in situ* work-loop experiments on rat plantaris muscle (n = 7) to determine the effects of increasing the internal mass of muscle on contractile performance. We also simulated the *in situ* experimental conditions using a mass-enhanced Hill-type muscle model to validate the results of the previous modelling studies. We found that experimentally increasing the mass of *in situ* muscle results in lower mechanical work per cycle, and this result was confirmed in the model simulations. Further, we found that this mass-dependent reduction in work is influenced by the muscle length change per contraction cycle, with greater length changes resulting in greater reductions in work. These results confirm that muscle mass is an important consideration for a complete understanding of whole muscle contractile behaviour.

5-7 ROSS, CF*; LAIRD, MF; GRANATOSKY, MC; University of Chicago, University of Southern California, New York College of Osteopathic Medicine; *rossc@uchicago.edu*
Energetic costs of locomotion and feeding in capuchin primates.
It is often assumed that natural selection minimizes energetic expenditure during cyclical feeding and locomotion so that energy might be allocated to growth, reproduction, predator avoidance, or mate competition. While this assumption has been supported in the locomotor system, the feeding system is small, and the muscles responsible for jaw opening and closing represent a mere fraction of total body weight. Because of this size disparity, we hypothesized that selection does not to minimize the metabolic costs of feeding. To test this hypothesis we measured respirometry-based metabolic energy expenditure during cyclic chewing and walking in tufted capuchin monkeys (*Sapajus* sp.) ranging in body size and metabolic costs. Mass-specific metabolic cost and cost per cycle during walking reached values up to ~15 times higher than cyclical chewing. During locomotion, we observed a negative relationship between the body size of the animal and the mass-specific metabolic cost, as well as the mass-specific metabolic cost per cycle. In contrast, both mass-specific metabolic cost and mass-specific metabolic cost per cycle increased along with body size during cyclical chewing. This result likely stems from anatomical and mechanical patterns in the feeding system inconsistent with energetic minimization, such as: a high proportion of myosin heavy chain masticatory isoforms known for their high rates of ATP consumption; relatively low joint angular excursions that correspond to higher than expected costs of movement; and a relatively stiff system that does not utilize passive mechanisms. Taken together, these features suggest that in the feeding system, minimizing energy costs may be less important than the control of force and displacement.

33-3 ROSSO, AA*; LOGAN, ML; MCMILLAN, WO; COX, CL; Georgia Southern University, University of Nevada Reno, Smithsonian Tropical Research Institute, Florida International University; *ar20855@georgiasouthern.edu*
Phenotypic Plasticity and the Response to Increasing Temperatures in a Tropical Lowland Lizard
Climate change is an important agent of selection on physiology and phenology, and can affect the range and distribution of organisms. Organisms may respond to climate change through behavior, genetic adaptation or phenotypic plasticity. However, these predictions are not consistent across latitude. Tropical ectotherms are predicted to be negatively impacted by climate change because 1) most have a narrow range of thermal tolerance while already living close to their thermal optima, and 2) they are thought to have decreased capacity for phenotypic plasticity because they have evolved in thermally stable environments. We used a mesocosm experiment to test the capacity for phenotypic plasticity of the Panamanian slender anole (*Anolis apletophallus*) under warming temperature. We caught lizards from Soberania National Park and randomly assigned an equal number of males and females to a control and warming treatment. We measured voluntary thermal maxima, critical thermal minima, and behavior in a thermal gradient before and after 28 days of treatment. We found that voluntary thermal maxima and maximum temperature chosen in a thermal gradient increased in the warm treatment, but not the control treatment. In contrast, we found that critical thermal minima and the mean temperature chosen in a thermal gradient decreased in both treatments. Our results provide evidence that tropical organisms can use phenotypic plasticity to respond to a changing climate, despite previous theoretical work suggesting that they lack plastic potential. This work highlights that phenotypic plasticity should be considered when predicting the future of tropical ectotherms under a changing climate.

95-3 ROSVALL, KA*; LIPSHUTZ, SE; Indiana University, Bloomington; *krosvall@indiana.edu*
Obligate cavity-nesting shapes the evolution of territorial aggression, but not testosterone, in both female and male birds
Our understanding of the proximate and ultimate mechanisms shaping competitive phenotypes primarily stems from research on male-male competition for mates, even though female-female competition is also widespread. Obligate secondary cavity-nesting provides a useful comparative context to explore the phenotypic effects of competition because this reproductive strategy has evolved repeatedly across avian lineages, and it is thought to generate strong competition for a pre-made cavity in which to nest, for both males and females. We tested the hypotheses that cavity-nesting elicits more robust aggressive responses to conspecifics and that this behavioral trait is facilitated by elevated testosterone levels in circulation in both sexes. We assayed aggression in males and females in two obligate cavity-nesting species and two related non-cavity-nesting species in the same avian family: tree swallow (*Tachycineta bicolor*) vs. barn swallow (*Hirundo rustica*); Eastern bluebird (*Sialia sialis*) vs. American robin (*Turdus migratorius*). We found that both male and female cavity-nesting species were more aggressive than their non-cavity-nesting close relatives. However, we did not find higher testosterone in cavity-nesting females or males, despite some correlative evidence that testosterone is associated with territorial defense. These patterns support the long-held hypothesis that cavity-nesting may select for greater territorial aggression in both sexes, but parallel increases in aggression are not associated with greater testosterone secretion in either sex.

100-3 ROWSEY, LE*; REEVE, C; SAVOY, T; SPEERS-ROESCH, B; University of New Brunswick, Saint John; *lrowsey@unb.ca*
Thermal Constraints on Anaerobic Exercise and Aerobic Performance are Not Major Drivers of Winter Dormancy in Cunner
Winter dormancy (an inactive, fasting, slow metabolism state) is used by certain fishes to endure the frigid and food-poor winter and persist at poleward latitudes. However, little is known about the mechanisms and drivers of winter dormancy. We hypothesized that winter dormancy arises because of severe constraints on physiological performance at frigid temperatures. To test this, we measured the thermal sensitivity of fitness-linked physiological performance (burst swimming, metabolic rate, and aerobic scope) and related biochemical characteristics (metabolite levels and enzyme activities) in the winter-dormant cunner (*Tautogolabrus adspersus*), which enters dormancy below 7.4°C on average. Performance was measured after acute exposure to 2-26°C and after acclimation (≥5 weeks) to 2-14°C. As expected, performance declined with cooling below the thermal optimum in both exposure groups. In acutely exposed fish, the thermal sensitivity of all performance traits was greater below the dormancy threshold temperature than above, suggesting a major constraint of cold. However, at 2°C, acclimated cunner had greater performance and lower thermal sensitivity compared to acutely exposed cunner (Q_{10} of 1.1-2.0 vs. 3.9-4.3 between 8-2°C, respectively). Thus, dormant cunner show partial compensation of swimming and aerobic performance in winter cold temperatures, similar to cold-active species. However, compensation of metabolic enzyme activities did not underlie the whole-animal performance compensation. We conclude that thermal constraints on anaerobic exercise and aerobic performance are not major drivers of winter dormancy in cunner.

S2-5 RUBENSTEIN, DR; Columbia University; *dr2497@columbia.edu*
Epigenetic Programming and the Evolution of Adaptive Coping
Stressors during development can influence physiology, phenotype, and ultimately fitness later in life. Such development programming can be both adaptive by preparing organisms to deal with environmental conditions later on, or it can be maladaptive by constraining organismal phenotypes no matter the type of environment experienced as adults. Although epigenetic changes that alter the structure of DNA are thought to be one of the primary mechanisms that underlie developmental programming, we lack a general understanding of how early life stressors impact epigenetic changes in the genome. Using superb starlings (Lamprotornis superbus), which inhabit a range of East African environments where conditions vary unpredictably from year-to-year, I will explore how early life conditions influence epigenetic programming. I will discuss how patterns of DNA methylation across the entire starling genome vary with rainfall during development, discussing the gene regulatory networks that show signatures of adaptive capacity versus those that show signatures of being constrained by early life conditions. Taking a more fine-scale approach, I will then focus on a suite of genes known to be related to stress and reproduction to determine how epigenetic programming acts at different scales to potentially alter physiology and fitness. Ultimately, I will not only illustrate the different ways that variable early life conditions shape patterns of DNA methylation across the genome, but I will develop an evolutionary framework for understanding adaptation and constraint in the context of developmental and epigenetic programming.

132-5 RUDDY, BT*; LONG JR, JH; VERMA, S; PORTER, ME; Florida Atlantic University, Boca Raton, Fl, Vassar College, Poughkeepsie, NY; *bruddy2018@fau.edu*
Swimming efficiency influences schooling position of volitionally swimming blacktip sharks.
Fish gain hydrodynamic benefits such as increased swimming efficiency when schooling. The group structure, or arrangement within a school, necessary for increased efficiency is modeled as four animals in a diamond formation, but this hypothesis has not been tested in the wild. Previously, we quantified wild *Carcharhinus limbatus*, blacktip sharks, volitional swimming kinematics and found individuals traveled in groups of 4, in a diamond formation, and had significantly lower Strouhal number values when compared to other group sizes. Here, we examine hydrodynamic models produced by our volitional swimming kinematics data. We utilized an aerial drone to capture footage of wild, straight swimming *C. limbatus* in various group sizes and used motion tracking software to examine kinematic variables (tailbeat frequency, amplitude, velocity, and Strouhal number). ImageJ was used to quantify nearest-neighbor distance, school density, orientation angle, and position within a formation from still photos. Kinematic data were then used as inputs for numerical simulations solving the Navier-Stokes equations to examine wake produced by varying group sizes (2-12 sharks). Reynolds' flocking models were used to assess coordination among sharks within a school. Our results indicate that individuals within a group are placed to interact constructively with wake, and coordinated movement exists within pairs of individuals. This work provides validation to previous mathematical simulations from the literature conducted on hydrodynamics of collective formations, and insight into priorities of schooling arrangements in the wild.

101-6 RUDZKI, EN*; KOHL, KD; STEPHENSON, JF; University of Pittsburgh; *elr82@pitt.edu*
Skin Microbiome Significantly Predicts Susceptibility to Ectoparasite Infection in Trinidadian Guppies, Poecilia reticulata
The role that microbes play in host-parasite interactions is currently poorly understood. In aquatic environments, the host-associated microbiome (HAM) of fish and salamander skin has been found to be highly important to their general health and ability to fend off other pathogens. Current research focuses primarily on end-infection dysbiosis, or an altered microbial state from normal thought to be caused by parasitic infection or activation of the immune system. Here, we were interested in elucidating whether the microbiome present on the host pre-infection could predict subsequent infection susceptibility to the parasite. To address this question, we used a monogenean ectoparasite, *Gyrodactylus turnbulli*, and its host the Trinidadian Guppy (*Poecilia reticulata*) to untangle the relationships between host, parasite, and the HAM. Guppies were either experimentally- or sham-infected with *G. turnbulli* and housed individually. The number of parasites present on each fish was counted every 48 hours, and we quantified each fish's infection susceptibility using the area under the curve of infection load over time. We swabbed fish skin to inventory the skin HAM before infection (Day 0) and during late infection (Day 15). We identified several bacterial taxa whose relative abundance in the skin HAM prior to infection significantly predicts subsequent *G. turnbulli* infection susceptibility (*Sphingobium*, *Agromyces*, *Methylococcaceae*, and *Gemmata*). Our results therefore demonstrate that skin microbiome community composition significantly predicts susceptibility to an ectoparasitic helminth. Future experiments will elucidate the mechanisms underlying this effect – do bacteria and parasite interact directly, indirectly, or are they correlates of a third process?

51-7 RUIZ, CA*; THEOBALD, JC; Florida International University; *cruiz093@fiu.edu*

Fruit Flies Respond to Ventral Parallax During Strong Sideslip Disturbances

Flies and other insects use incoherent motion (parallax) to the front and sides to measure distances and identify obstacles during translation. Although additional depth information could be drawn from below, there is no experimental proof that they use it. The finding that blowflies encode motion disparities in their ventral visual fields suggests this may be an important region for depth information. We used a virtual flight arena to measure optomotor responses to unintended sideslip and rotational optic flow in fruit flies. The stimuli appeared below (n=51) or above the fly (n=44), at different speeds, with or without parallax cues. Dorsal parallax does not affect responses, and similar motion disparities in rotation have no effect anywhere in the visual field. But responses to strong ventral sideslip (70 deg/s) change drastically depending on the presence or absence of parallax (p=0.023). Ventral parallax could help resolve ambiguities in cluttered motion fields, and enhance corrective responses to nearby objects.

50-4 RUPP, AE*; MOON, B; University of Louisiana Lafayette; *arianarupp91@gmail.com*

Feeding and Digestive Anatomy of Mud Snakes

Mud snakes are dietary specialists that regularly consume elongate amphibian prey such as siren and amphiuma salamanders. This study described the unique feeding behaviors of adult and juvenile mud snakes on elongate prey items using video recorded feeding trials. The digestive anatomy of both adult and juvenile mud snakes is also described in order to identify any specialized structures of the digestive tract that may aid in the consumption of elongate salamanders. Both gross morphology and histology of the digestive tract are described.

133-4 RUMMEL, AD*; FAURE, PA; SMOTHERMAN, MS; SWARTZ, SM; MARSH, RL; Brown University, Providence, RI, McMaster University, Hamilton, ON, Texas A&M, College Station, TX; *andrea_rummel@brown.edu*

Is Reduced Thermal Sensitivity in Distal Wing Muscles a Functional Adaptation to Bats' Unique Wing Morphology?

Bat wings contain muscles whose fast, coordinated contractions are integral to the flight stroke. Muscle cooling slows contractile rates, however, and flight exposes bats to substantial convective and radiative heat losses. Since bat wings are poorly thermally insulated, a temperature gradient exists from the proximal core (warm) to the distal periphery (cool). During flights at ~22°C, in *Carollia perspicillata* the distal extensor carpi radialis longus muscle (ECRL) operates at ~12°C below core body temperature (T_b) while the proximal pectoralis muscle operates near T_b. The ECRL is also less temperature sensitive than the pectoralis, i.e., it experiences a proportionately smaller decline in contractile rates after a given drop in temperature. This finding raises an important question: Is this high-to-low gradient in temperature sensitivity from proximal-to-distal in the bat wing a functional adaptation to the wing's local thermal environment, or the climate in which the bats live? To address this, we measured contractile rates in the ECRL and pectoralis muscles of *C. perspicillata* and *Eptesicus fuscus*, and in the ECRL muscle of *Tadarida brasiliensis* at a range of experimental temperatures (22–42°C) to determine if muscle temperature sensitivity varies interspecifically. There was little difference in the thermal sensitivities of the ECRL or pectoralis muscles between species; however, the ECRL was less temperature sensitive than the pectoralis. These results suggest that the low temperature sensitivity of the ECRL muscle in bats may be due to local thermal challenges rather than as an adaptation to largescale environmental conditions.

67-5 RUSSELL, A; BORRELLI, S; FONTANA, R; LARICCHIUTA, J; PASCAR, J; BECKING, T; GIRAUD, I; CORDAUX, R; CHANDLER, CH*; SUNY Oswego, SUNY Oswego, Syracuse University, Université de Poitiers; *christopher.chandler@oswego.edu*

A Transition to XY Sex Chromosomes Associated with Y-linked Duplication of a Male Hormone Gene in a Terrestrial Isopod

Sex chromosomes have evolved independently and repeatedly in a wide range of taxa. In some groups, the sex chromosomes are relatively stable, having been conserved for millions of years, while in others, the sex chromosomes undergo frequent turnovers. One possible explanation for the high frequency of turnovers in some organisms is the presence of reproductive endosymbionts such as *Wolbachia*. In terrestrial isopods, for instance, *Wolbachia* can induce host feminization and is thought to drive rapid sex chromosome turnover in this group. The terrestrial isopod *Trachelipus rathkei*, which is widespread throughout North America and Europe, is described as having a ZZ/ZW sex chromosome system in a cytogenetics study. We tested this hypothesis using crosses with experimentally sex-reversed individuals, and surprisingly found that sex is determined by an XX/XY system in our population. Moreover, genomic sequencing and PCR found evidence of past *Wolbachia* infections, plus a male-specific, Y-linked duplication of the androgenic gland hormone gene, which triggers male development in isopods. These results support the idea of frequent transitions in isopod sex chromosomes, and suggest that hosts may evolve mechanisms to counteract the effects of reproductive endosymbionts.

88-3 RUTLEDGE, KM; University of California Los Angeles; *kelsimarie7@g.ucla.edu*
Sniffing out batoid nasal morphology: a model for classification with functional implications
Batoids (rays, skates, sawfishes and guitarfishes) possess a suite of sensory modalities, including vision, hearing, mechanoreception, electroreception, and olfaction. Olfaction is the longest-range sense and is crucial for initial detection of a stimulus and long-range tracking. Olfactory processes are directly tied to, or have implications for: navigation and tracking, food recognition, reproductive signaling and conspecific recognition, and predator avoidance. The anatomy (internal and external) and placement of the olfactory apparatus in batoids is highly divergent from the more recently evolved bony fish relatives (e.g. trout, tuna). Batoid species, while exhibiting considerable morphological and ecological diversity as a group, are all dorsoventrally flattened, with eyes on the opposite side of the head from their nose and mouth. They also possess an unusual nose, enlarged relative to other fishes, with numerous external flap-like structures or projections. Nasal diversity within the group is disparate, with differences in size, position, and angle of the nares, as well as the number of nasal flaps. I hypothesize that the nasal diversity displayed in this group corresponds with functional rather than phylogenetic differences. In order to quantify shape diversity, I created a morphometric model of snout and nasal differences across 15 families and 50 species. Using this model along with CT data, I propose classifications of nasal morphotypes displayed in batoids with functional and ecological implications.

99-2 RYAN, DS*; DOMINGUEZ, S; NIGAM, N; WAKELING, JM; Simon Fraser University; *dsryan@sfu.ca*
Mechanisms that Relate Transverse Loading of Muscle to Change in Contractile Performance
Muscles exist in confined spaces, packed in between organs, muscles, bones, and skin. Due to this, any bulging that a muscle undergoes will result in a load on that muscle or another muscle. Experimental work has shown that muscles produce less force when contraction simultaneously. Further experimental work has shown that transverse load on a muscle can lead to a reduction in force production when either unidirectional or multidirectional loading is applied. Our aim is to replicate such loading experiments using a muscle model to probe the mechanisms behind this effect. Here we use a three-dimensional finite element model of muscle based on the mechanics of fibre-reinforced composite biomaterials. The model represents both the passive and active fibre force-length properties, as well as base material properties that include the non-fibre elements such as extracellular matrix, connective tissues, blood vessels, and nerves. The model is written in C++ built on the deal.II finite element library. The model allows the testing of unidirectional and multidirectional loading from transverse directions on various pennate and parallel muscles and the quantification of the resulting changes in muscle architecture and stress. Simulated compressions demonstrate the changes in the muscle force when transverse load is applied, and show that this is a multifactorial phenomenon dependent on both loading conditions and internal architecture.

125-6 RYDER, TB; DAKIN, R*; VERNASCO, BJ; EVANS, BS; HORTON, BM; MOORE, IT; Smithsonian Institution, Carleton University, Virginia Tech, Millersville University, Virginia Tech; *roslyn.dakin@gmail.com*
Testosterone modulates status-specific patterns of cooperation in a social network
Stable cooperation requires plasticity whereby individuals are able to express competitive or cooperative behaviors depending on social context. To date, however, the physiological mechanisms that underlie behavioral variation in cooperative systems are poorly understood. We studied hormone-mediated behavior in the wire-tailed manakin (*Pipra filicauda*), a gregarious songbird whose cooperative partnerships and competition for status are both crucial for fitness. We used automated telemetry to monitor > 36,000 cooperative interactions among male manakins over three field seasons, and we examined how circulating testosterone affects cooperation using > 500 hormone samples. Observational data show that in non-territorial floater males, high testosterone is associated with increased cooperative behaviors and subsequent ascension to territorial status. In territory-holding males, however, both observational and experimental evidence demonstrate that high testosterone antagonizes cooperation. Moreover, circulating testosterone explains significant variation (2-8%) in social behavior within each status class. Collectively, our findings show that the hormonal control of cooperation depends on a male's social status. We propose that the status-dependent reorganization of hormone-regulatory pathways can facilitate stable cooperative partnerships, and thus provide direct fitness benefits for males.

S9-10 RYERSON, WG; Saint Anselm College; *wryerson@anselm.edu*
Captive breeding alters head morphology and behavior in reptiles: implications for headstarting and reintroduction programs
The use of captive breeding for the purpose of supplementing imperiled species is commonplace throughout herpetology, and continues to grow with each decade. For snakes, many of these programs take the form of "headstarting" programs. Individuals are born in captivity, and raised for as many as three years before reintroduction into the wild. The focus of these programs are maintaining genetic diversity in their captive populations, and ensuring that individuals survive to reproduce in the wild. However, it is not clear how the captive rearing environment may play a role in the behavior and morphology of these individuals, and how changes in the behavior and morphology influence the success of individuals upon reintroduction. Examination of feeding behavior across 10 different species of snake reveals that species respond differently to captive care protocols, in terms of strike performance, sensory biology, and prey-handling behaviors. Experimental manipulation of diet in newborn garter snakes, *Thamnophis sirtalis*, reveal that while total mass of food consumed ultimately drives body size, the size of individual food items can drive differences in head shape during the earliest stages of ontogeny. Changes in head shape may impact the ability of individuals to exploit resources later in life, and help drive the likelihood of survival. The additive effects of changes to both behavior and morphology from the native population is likely to alter the likelihood of success of the individual, and the reintroduction program. Taking steps to prevent these changes may increase that likelihood of success.

S3-10 SADIER, A*; DESSALES, R; SANTANA, S; SEARS, K; UCLA, University of Washington; *asadier@ucla.edu*
Finding new rules for the patterning and shape of mammalian dentition: insights from Noctilionoid bats
Teeth are ones of the most diverse organs in term of morphology. However, most of the extensive developmental work that has been done in mammals is based on mouse which exhibit a very derived dentition. Here, we take the advantage of the ~200 species of noctilionoids bats that encompass nearly all possible mammalian diets. In consequence, noctilionoids have evolved a wide diversity of post-canine dentition morphologies providing a natural experiment with which to investigate the developmental basis of morphological diversification. We will present a new model for the patterning of the mammalian post-canine dentition using this group as a reference. By combining morphometric and quantitative data from 117 adult species, we showed that the number of post-canine teeth is related to the length of the jaw and that premolar and molar proportions are independent, suggesting distinct developmental mechanisms for their formation. To get insight into these underlying mechanisms, we analyzed the development of 12 species across 8 developmental stages by μCT scan and tested markers. We also injected pregnant bats with EdU to link teeth formation to the growth rate of the jaw. Finally, we proposed a new Turing-based model to explain the development of premolars and molars rows. Our data reveal that the premolar and molar rows are established by two independent signaling mechanisms and that teeth number and size is linked to the local growth rate of the jaw. We believe that this work provides a testable framework for other bats and mammals. Then, we present new data on the relationship between molar traits and the underlying gene regulatory networks (GRNs) and pathways, using bat molar as a foundation to test the existence of developmental modules in GRNs that control shape variation. We will present morphological and computational models using machine learning as well as experimental data.

106-1 SAENZ, DE*; WINEMILLER, KO; MARKHAM, MR; Texas A&M University, University of Oklahoma; *dsaenz@tamu.edu*
Derived Loss of Signal Plasticity in a Genus of Weakly Electric Fish
Signal plasticity can maximize the utility of costly animal signals. This is especially true for multi-functional signals such as the electric organ discharges (EODs) of weakly electric fishes. How this plasticity affects the functional and behaviorally relevant properties of animal signals is not fully understood. We compared signal plasticity in four species of *Brachyhypopomus*, a genus of weakly electric fishes (Gymnotiformes, Hypopomidae). Regulated by adrenocorticotropic hormone (ACTH), this type of EOD plasticity allows some species to increase their EOD amplitude in response to circadian cues and social stimuli. ACTH-induced amplitude changes occur via different mechanisms, possibly the rapid trafficking of ion channels to the membranes of the electrocytes (electric organ cells), or by regulating ion channel kinetics. We used *in vivo* injections and *in vitro* electrophysiology to study the effects of ACTH on the behavior of whole fish and individual electrocytes. We also used immunolocalization to map the distribution of ion channels within electrocytes, which contributes to the species-specific EOD waveform. We predicted that the monophasic species, *B. bennetti*, would show increased EOD amplitude plasticity relative to congeners with biphasic EODs. We further predicted that voltage-gated sodium channels would only be present on the innervated posterior membrane as in another monophasic gymnotiform, the Electric Eel. Surprisingly, *B. bennetti* shows significantly less EOD amplitude plasticity compared to closely related biphasic species. Further, we found that sodium channels are present on both electrocyte membranes and that a second action potential drastically reduces the overall head-positive current, likely at great metabolic cost.

S10-9 SALCEDO, MK*; HOFFMANN, J; DONOUGHE, S; COMBES, SA; MAHADEVAN, L; Virginia Tech, Blacksburg, VA, Harvard University, Cambridge, MA, University of Chicago, Chicago, Illinois, University of California, Davis, CA; *maryksalcedo@gmail.com*
What's in a vein? Using computational tools to explore wing diversity and functional consequences of venation patterns on hemodynamics
Insect wing venation patterns are highly diverse, with some wings partitioned into just a few "domains" (vein-bounded regions) and others into many thousands. To characterize the spectrum of insect wing patterns and compare venation and topologies across insect orders, we created quantitative tools to explore wing geometries. We amassed an unprecedented dataset of scanned insect wings and segmented these wings into features of size, shape, and structure. We analyzed simple morphospaces to compare wings of relatively "dense" and "sparse" venation (e.g. dragonfly versus fruitfly, respectively). Further, to investigate an important function of venation patterning and potential driver in wing diversification, we investigated circulation patterns of hemolymph flow within the wings. Insect wings are dynamic living structures composed of networks of stiff tubular veins, which act as conduits that supply hemolymph to veins containing tracheae and nerves. In addition, sensory hairs and mechanosenosors require a continuous supply of hemolymph. With focus on an insect with complex venation (*Schistocerca americana*, the North American Grasshopper), we quantified hemolymph flow dynamics within adult fore- and hind-wings and determined hemodynamic relationships to accessory pulsatile organs such as wing hearts.This talk will highlight the diversity and multifunctionality of insect wings, and reflect on their development, function, and form, all of which play a role in the phylogenetic and functional diversity of insect wings.

102-6 SANDFOSS, MR*; CLAUNCH, NM; STACY, NI; ROMAGOSA, CM; LILLYWHITE, HB; University of Florida, Gainesville, Florida; *mrsandfo@ufl.edu*
A tale of two islands: stress response and immune function of an insular pit viper following ecological disturbance.
The frequency and intensity of ecological perturbation is expected to increase in the future with animals facing multiple global threats. Our ability to assess the response of free-ranging animals to a stressor is vital to our understanding of how animals cope with ecological disturbance. Seahorse Key is a continental island in the Gulf of Mexico that has historically been the site of a major waterbird rookery. The island also supports a population of Florida cottonmouth snakes (*Agkistrodon conanti*), which has a unique trophic association with nesting waterbirds. In April 2015 the waterbirds completely abandoned the island for nesting purposes and shifted nesting activities and subsequently all food resources to nearby Snake Key. This study takes advantage of this natural ecological "experiment" to evaluate plasma corticosterone, blood glucose, natural antibody agglutination, hemogram, and erythrocyte sedimentation rate to characterize the long-term effects of differential resource availability of two populations in situ. In fall 2018, we collected blood samples at three time points from cottonmouths on Seahorse Key (n = 6) and Snake Key (n = 13). Our results suggest three years after the shift in waterbird nesting Seahorse Key cottonmouths exhibit lower body condition, a dampened acute stress response, and suspected impaired innate immune functions relative to cottonmouths on Snake Key. Our results highlight the context-dependent nature of physiological biomarkers and suggests that the reduced availability of energy on Seahorse Key has resulted in an inability to maintain adequate stress responses and innate immune functions.

101-7 SANDMEIER, FC*; LEONARD, KL; WEITZMAN, CL; TRACY, CR; BAYER, B; BAUSCHLICHER, S; Colorado State University-Pueblo, Virginia Polytechnic Institute and State University, University of Nevada, Reno; *fcsandmeier@gmail.com*
Indirect, facultative interaction between a commensal microbe and an opportunistic pathogen in the tortoise respiratory tract
Within the medical literature, there is a growing awareness of the complex interactions – even among commensal species – that may cause polymicrobial diseases and increase virulence of opportunistic pathogens. Despite evidence that *Mycoplasma agassizii* causes a respiratory disease in tortoises, other, unknown factors influence the severity and recrudescence of disease. We used a quantitative PCR to compare loads of a commensal, common microbe (*Pasteurella testudinis*) and the opportunistic pathogen (*M. agassizii*) in nasal lavage samples obtained from 389 Mojave desert tortoises (*Gopherus agassizii*). We show that animals with *P. testudinis* have higher loads of *M. agassizii*, which is associated with a higher risk of disease. However, the prevalences of the microbes were not associated with each other, and the presence of both microbes did not predict a higher probability of disease. We used a captive, *M. agassizii*-naïve colony of healthy tortoises to verify that *P. testudinis* alone does not cause disease and is a prevalent member of both the nasal and cloacal microbiomes. We are exploring techniques to understand this possible indirect, facultative interaction between the two microbes, including the possibility of cross-feeding. Cross-feeding occurs when one microbe makes nutrients available to another species of microbe, influencing its persistence or growth rates inside the host. Such mechanisms can include enzymes such as sialidase, which can cleave glycoprotein components of the mucous and provide additional nutrients for microbial growth.

132-3 SANTHANAKRISHNAN, A*; FORD, MP; Oklahoma State University; *askrish@okstate.edu*
(Un)synchronized rowing: importance of phase lag in metachronal swimming performance
Metachronal swimming is a common method of drag-based aquatic locomotion in which a series of swimming appendages are stroked in an oscillatory pattern, such that the movement of each appendage is delayed in time relative to the neighboring appendage. It is often used by crustaceans and other ecologically important marine invertebrates. We developed a dynamically scaled self-propelled robotic model for a comparative study of metachronal swimming performance under varying inter-appendage phase lag. Appendage motion profiles were obtained from published hovering and fast-forward swimming kinematics of *Euphasia superba* (Murphy et al., Mar. Biol., 158, 2011), but the phase lag between adjacent appendage pairs was varied. Time-resolved particle image velocimetry measurements show that interaction between shear layers of adjacent paddling appendages results in the formation of a continuous wake jet directed in the caudoventral direction. Swimming performance was characterized by the maximum swimming speed of the self-propelling model, as well as the forward force generated by the model when tethered. Results show that phase lags of 15% and 25% of cycle time, close to the phase lags reported for *E. superba*, result in the best forward swimming performance when compared to phase lags of 0, 35, and 50%.

S7-7 SANTOS, SR*; HOFFMAN, SK; SEITZ, KW; HAVIRD, JC; WEESE, DA; Auburn University, Alabama, Green River College, Washington, University of Texas at Austin, Texas, University of Texas at Austin, Texas, Georgia College and State University, Georgia; *santos@auburn.edu*
Phenotypic Comparability Arising from Genotypic Variability amongst Physically Structured Microbial Consortia
Microbiomes, representing the collective microbial community living in or on an individual, are recognized as having significant impacts on the development, health, and disease status of multicellular hosts. Given that the mechanistic basis between an individual's genome and phenome requires consideration at different levels of biological organization, this should include interactions with, and the organization of, microbial consortia. As another model in understanding consortia organization, we elucidated the genetic constituents amongst phenotypically similar (and hypothesized functionally-analogues) layers in the unique laminated orange cyanobacterial-bacterial crusts endemic to Hawaii's anchialine ecosystem. High-throughput amplicon sequencing of ribosomal RNA hypervariable regions revealed microbial richness increasing by crust layer depth, with a given layer more similar to different layers from the same geographic site than to their phenotypically analogous one from different sites. Furthermore, samples from sites on the same island were more similar to each other, regardless of which layer they originated from, than to analogous layers from another island. Notably, cyanobacteria and algae were abundant in all surface and bottom layers, with anaerobic and chemoautotrophic taxa concentrated in the middle two layers, suggesting oxygenation from both above and below. Thus, arrangement of oxygenated vs. anoxygenated niches in these orange crusts are functionally distinct relative to other examined laminated cyanobacterial-bacterial communities, with convergent evolution due to similar environmental conditions a likely driver for these phenotypically comparable but genetically distinct microbial consortia.

79-7 SASSON, D*; JOHNSON, T; SCOTT, E; FOWLER-FINN, K; Saint Louis University; *sassonda@slu.edu*
Water deprivation affects mating behaviors and outcomes in the harvestman, Leiobunum vittatum
Individual variation in resource acquisition prior to mating can influence mating dynamics. Water is one resource that may impact reproduction, but little is known how variation in individual hydration status affects mating behaviors. Here, we investigate the effects of short-term water deprivation on mating behavior in the harvestman, *Leiobunum vittatum. Leiobunine harvestmen follow stereotyped stages of mating, with the potential for female resistance to end the interaction at each stage: males first embrace (clasp) females, then copulate, and some males guard females after mating. We ran single choice mating trials between males and females that were either deprived or not deprived of water for four hours prior to interacting to determine how water deprivation affects mating dynamics across each stage. Our results indicate that water deprivation impacts multiple stages of mating, with the stage of reproduction affected depending on whether the male or the female was water-deprived. These results suggest that short periods of water deprivation can alter mating behaviors and may be an important, but understudied, factor in sexual selection research.*

79-5 SAYAVONG, N*; ESTRADA, M; SALAS, H; GUNDERSON, AR; STILLMAN, JH; TSUKIMURA, B; California State University, Fresno, Tulane University, San Francicso State University; *sayavongnathan@gmail.com*

Effects of preferred temperature, interspecific interactions, and increased population density on vitellogenesis on intertidal crabs Petrolisthes cinctipes and Petrolisthes manimaculus

Increased temperatures from global warming can lead to lethal temperatures for the intertidal crabs *Petrolisthes cinctipes* and *P. manimaculus* (Decapoda: Anomura). Physiological stress from increased temperature may force *P. cinctipes* redistribution into cooler environments (Stillman and Somero 1996). However, these crabs have a preferred temperature (15.0±0.4 °C) that is higher than their ambient temperature, 12 °C (Gunderson et al. 2019). To investigate the effects the preferred temperature on vitellogenesis, *P. cinctipes* and *P. manimaculus* were collected from November 2018 through July 2019 and exposed to their preferred temperature and placed at high and low densities with conspecifics and congeners. Hemolymph samples were taken from each crab before and after seven-day density and temperature treatments. To quantify the effects of treatments, an ELISA was used to quantify vitellogenin levels in hemolymph before and after treatment (Delmanowski et al. 2017). During winter months, *P. cinctipes* showed decreased vitellogenesis when exposed to thermal stress (20 °C) (Salas 2017). Exposing *P. manimaculus* to preferred temperatures increased vitellogenesis. These data support that the preferred temperature of *P. cinctipes* and *P. manimaculus* is 15.0±0.4 °C (Gunderson et al. 2019). Research reported in this abstract is supported by NSF grant #1451423 to BT and JS.

67-7 SCEPANOVIC, J*; KOLCHENKO, S; PLESSIER, F; LOWE, C; SPITZ, F; MARLOW, H; University of Chicago and Pasteur Institute, Paris and École normale supérieure, Paris, University of Chicago and Pasteur Institute, Paris and Sorbonne Université, Paris, Stanford University, University of Chicago and Pasteur Institute, Paris; *scepanovic@uchicago.edu*

Modularity in Gene Regulation: Evolution of Combinatorial Cis-Regulatory Inputs

The 3D structure of chromatin is tightly linked to gene expression regulation. It is yet unclear how folding mechanisms may ensure robust and specific gene expression in non-vertebrate lineages. We aim to understand how the 3D folding of the genome impacts the cell-type specific transcriptional program via the interaction of cis-regulatory elements (CREs) with gene promoters. In order to do this, we have examined 3D chromatin structure, regulatory interactions and gene expression in an early-branching deuterostome *Saccoglossus kowalevskii* and the sea anemone *Nematostella vectensis*. We first identified CREs using ATAC-Seq and motif scanning computational methods and promoters via 5' transcript mapping (Tn5Prime). We investigated regulatory interactions involving transcription factor (TF) promoters by performing Capture Hi-C. We computationally identified *Saccoglossus* TFs and characterized their binding specificity. We find that the use of alternative promoters is present in both *Saccoglossus* and *Nematostella*, possibly contributing to cell identity; TF promoters interact with multiple CREs in both species; and regulatory interactions spread through longer distances in *Saccoglossus* than in *Nematostella*. Our data has made progress in understanding the relationship between invertebrate 3D genome structure and regulatory interactions. Ultimately, we aim to combine our understanding of 3D gene regulation via CREs with developmental data on the role of TFs to generate a more complete picture of context-specific gene regulation in invertebrates.

S7-9 SCHAEFER, RJ*; BAXTER, I; MCCUE, ME; University of Minnesota, St Paul, MN, Donald Danforth Plant Science Center, St Louis, MO; *rob@linkage.io*

Using Camoco to integrate genome-wide association studies with context specific co-expression networks in corn and horses

High throughput technologies are currently a major driver for genetic improvement in many domestic and ecological plant and animal species. In the past decade, genome wide studies (GWAS) have associated changes in DNA to variation in phenotypes of interest. Hundreds of links between genetic markers (SNPs) and important traits have been identified by GWAS. Yet, the causal gene/allele often remains unknown due to many genes being in linkage disequilibrium (LD) with each of potentially dozens of genetic markers. Co-expression networks identify genes that share similar response patterns of gene expression, making them a powerful tool for inferring the biological function of under-characterized genes. In the right biological context, sets of causal genes related to a GWAS trait will exhibit strong co-expression while inconsequential genes in LD with the marker exhibit random patterns of co-expression. Here, we showcase the functionality of Camoco, a computational framework developed to integrate GWA studies with gene co-expression networks. Camoco was used to build gene co-expression networks in many species, however this talk will focus on demonstrative use-cases in maize and the domestic horse. Using Camoco, we built gene co-expression networks in several different biological contexts. Networks were benchmarked for biological signal using curated ontologies (e.g. GO) as well as unsupervised network clustering. Once vetted, networks are used to interpret and prioritize GWAS data using an integrative "overlap" algorithm. Genes are prioritized based on the strength of co-expression among other GWAS tagged genes. Camoco is open source software and available at github.com/LinkageIO.

S8-10 SCHIEBEL, PE*; LIN, B; HUBBARD, AM; CHEN, L; BLEKHERMAN, G; GOLDMAN, DI; Georgia Institute of Technology; *perrin.schiebel@gatech.edu*

Specialization of control strategies in terrestrial slithering snakes.

While traditionally viewed as obstacles to in locomotion, limbless locomotors must use heterogeneities for propulsion. We challenged snakes to traverse a model heterogeneous terrestrial terrain---rigid arrays of posts on a whiteboard substrate. We studied two species adapted to different habitats, the desert specialist shovel-nosed snake *C. occipitalis*, which we previously found used open-loop control supplemented by passive mechanics to negotiate the sparse obstacles in its sand-dominated environment [Schiebel et al. PNAS 2019], and the generalist corn snake *P. guttatus* whose natural range includes a variety of terrains. Principal component analysis (PCA) revealed the specialist's stereotyped sand-swimming wave was omnipresent during motion through the arrays, while results for the generalist were inconclusive, suggesting either the snakes did not have a preferred waveform or two dimensions were not adequate to describe the kinematics. We applied persistent homology, a mathematical technique to search for periodic data without reducing dimension, and found the specialist had long cycles consistent with PCA. The generalist, however, had fewer and shorter cycles, indicating the kinematics were aperiodic. We hypothesized that the generalists were instead targeting a desired pattern of reaction forces and tested this using a simplified terrain, a single force-sensitive post on the whiteboard. Generalists maintained contact with the post for longer durations and had less variation in the direction of the resulting force vector than the desert snake. Our study suggests control specialization; the specialist targets beneficial sand swimming kinematics while the generalist controls for advantageous force generation in accord with early studies of generalist snakes in lattices [e.g. Gray 1955].

140-4 SCHNITZLER, CE; NGUYEN, AD; KOREN, S; BARREIRA, SN; GONZALEZ, P; CHANG, ES; PHILLIPPY, A; MULLIKIN, JC; CARTWRIGHT, P; NICOTRA, ML; FRANK, U; BAXEVANIS, AD*; U. Florida, NHGRI/NIH, U. Kansas, U. Pittsburgh, NUI-Galway; *andy@mail.nih.gov*
The Genomics of Hydractinia: Understanding Regeneration, Allorecognition, and Stem Cell Biology
The cnidarians – organisms unified in a single phylum based on their use of cnidocytes to capture prey and defense from predators – occupy a key phylogenetic position as the sister group to the bilaterians. Given their experimental tractability and great potential for studying regeneration and allorecognition, we have sequenced and annotated the genomes of two cnidarian species: *Hydractinia echinata* and *Hydractinia symbiolongicarpus*. The remarkable regenerative capacity of these species is conferred by migratory interstitial cells (or i-cells) that are pluripotent, expressing genes whose bilaterian homologs are known to be involved in stem cell biology. Using PacBio, Illumina, and Dovetail-based strategies, high-coverage sequencing data indicate a genome size of 774 Mb for *H. echinata* (84x coverage) and 514 Mb for *H. symbiolongicarpus* (94x); these genomes are AT-rich (65%) and highly repetitive (>46%). The vast majority of evolutionarily conserved single-copy orthologs have been identified in these assemblies, and analyses of these whole-genome sequencing data have already provided important insights into the evolution of chromatin compaction and sex determination. These data have also revealed a heretofore-underappreciated complexity of the mechanisms controlling allorecognition in these colonial organisms with the discovery of a new set of candidate allorecognition genes. Our genome-scale data have established a strong foundation for identifying evolutionary novelties contained within these genomes and for functional studies aimed at identifying new targets for therapies in regenerative medicine.

47-6 SCHREY, A*; MILLER, K; LOGGINS, F; WIECZOREK, P; MCCOY, E; MUSHINSKY, H; Georgia Southern University Armstrong Campus, Dartmouth College, University of South Florida , University of South Florida; *aschrey@georgiasouthern.edu*
Epigenetic and Genetic Characteristics of Dispersal of the Florida Sand Skink
Home range and dispersal are fundamental ecological characteristics of a species and molecular markers can provide insights into the consequences of these characteristics. Knowledge of these factors is critical for fine-scale habitat management in a conservation framework. Here, we report an epigenetic and genetic investigation of the Florida Sand Skink to determine its fine-scale dispersal. This small, fossorial lizard is listed as threatened and a species of greatest conservation need. They are precinctive to the highly imperiled Florida scrub habitat, which is fire dependent, highly heterogenous, and now exists as a series of fragmented habitat patches. We use multiple microsatellite loci to screen genetic characteristics and epiRADseq to measure DNA methylation. We address the molecular rationale of why individuals disperse, answer the basic question of how far they disperse, and estimate their home range size. We characterize the spatial patterns of genetic relatedness among individuals, how relatedness affects dispersal, and how the genetic and epigenetic characteristics of individuals change with distance. Specifically, we will determine if more closely related individuals disperse further, or more generally, if there is a predictable molecular signature of dispersal. Finally, we integrate these data with previously collected data from multiple scrubs across the range of the Florida Sand Skink to investigate the driving factors of epigenetic and genetic characteristics among scrubs.

90-3 SCHUECH, R*; TOR NIELSEN, L; HUMPHRIES, S; SMITH, D; KIØRBOE, T; University of Lincoln, Technical University of Denmark, University of Birmingham; *rudi.schuech@gmail.com*
Hydrodynamics Shed Light on Dinoflagellate Evolution
Flagella are crucial to the interactions of many unicellular organisms with their surrounding aquatic environment. The dinoflagellates have a unique but remarkably conserved flagellation morphology: a trailing longitudinal flagellum and an exquisitely complex transverse flagellum that encircles the cell. What are the selective advantages offered by this arrangement? We investigate the dinoflagellate design *in silico* using a high-performance regularized Stokeslet boundary element method and combine these simulations with particle image velocimetry (PIV) observations of dinoflagellate-generated flow fields and swimming kinematics. We find that the helical transverse flagellum provides most forward thrust and, despite its near-cell position, is more hydrodynamically efficient than the trailing flagellum; however, the latter is nonetheless required to enable steering. Flagellar hairs and the sheet-like structure of the transverse flagellum allow dinoflagellates to exert strong propulsive forces and maintain high clearance rates without extending a long conventional flagellum far into the surroundings. This unique morphology has thus been essential to the evolution of the generally large, fast-swimming dinoflagellates.

9-3 SCHULZ, AK*; AYALA, J; ZHAO, W; RONG, H; HU, DL; Georgia Institute of Technology School of Mechanical Engineering, Chengdu Panda Base for Giant Panda Breeding - Husbandry and Reproduction, Georgia Institute of Technology School of Mechanical Engineering and Biology; *akschulz@gatech.edu*
Panda Cub Climbing for Conservation
A juvenile panda's best defense against predators is its ability scamper up a tree. Although climbing has been studied in black bears and the red squirrel, it has yet to be systematically in pandas. We designed and built a table-like structure with legs of diameters comparable to the trees found in their natural environment and tested 8 panda cubs ranging from 14-16 months old at the Chengdu Research Base for Giant Panda Breeding in the Sichuan province in China. Pandas climb up to speeds of speeds 0.1 to 0.3 m/s, and in a helical fashion, angling their body up 40 degrees from the vertical, and performing one cycle per meter. The 8 pandas exhibit a range of predilections for climbing, with 4 pandas have a much higher climbing success rate of 40% and above . We use these metrics to grade the panda cubs, which will provide useful input in deciding which pandas will have the greatest chance of survival when reintroduced into the wild.

22-5 SCHUMM, MR*; CUMMINGS, ME; RAMSEY, ME; UT; *mschumm13@gmail.com*
Testing cognitive flexibility in non-model organisms: Poeciliid fishes vary by species, sex and context in detour performance
Cognitive performance varies between species, and differences in life history characteristics may explain much of that variation. We compare variation in cognitive flexibility and problem solving in two live-bearing poeciliid fish species with different mating systems and invasive tendencies using the detour paradigm, in which individuals must innovate to circumnavigate a transparent barrier to reach a target. *Gambusia affinis* are highly invasive fish with exclusively coercive males, whereas *Limia perugiae* are noninvasive with polymorphic male mating phenotypes. We tested fish in a transparent-barrier detour maze with a female conspecific or predator lure target and in an opaque-barrier control. Performance in the maze was analyzed across species, sexes, and detour contexts for likelihood to solve and time measures for motivation and solving speed. We found no species difference in likelihood to solve or solving speed; however, *G. affinis* fish reached the barrier faster than *L. perugiae*, and both species reached the barrier fastest with a predator target. While neither species demonstrated sex differences in solving speed, *G. affinis* males were significantly more likely than females to solve both transparent detour contexts. Motivation to reach the barrier did not predict solving speed; yet we found a context and sex-dependent correlation between baseline anxiety/exploration in *G. affinis* males but not females. Specifically, high anxiety correlated with slow solving speed in the opaque context but correlated with fast solving speed in the predator context. These data indicate species and sex-dependent variation in detour performance may be driven by distinct life history characteristics (mating systems and invasiveness) and modified by sex-biased patterns in dispersal and noncognitive behavior.

25-4 SCHWAB, RK*; JANKAUSKI, MA; Montana State University; *rschwab03@gmail.com*
Efficient Modeling of Fluid-Structure Interaction in Single Degree-of-Freedom Flapping Wings
Flapping insect wings deform under both inertial and aerodynamic forces. This fluid-structure interaction (FSI) is beneficial to aerodynamic performance and energetic efficiency. However, many flapping wing FSI models rely on direct numerical methods and require considerable computational resources to solve. Here, we present a simple, analytic FSI model for a wing subjected to single degree-of-freedom flapping that can be solved with minimal computational effort. The structural model is developed via the Lagrangian formulation and fluid loading is accounted for through a blade element approach that considers lift, drag and added mass forces. We validate this model experimentally by flapping a paper wing both in air and in vacuum using a custom rotation stage and recording strain at the base of the wing. Agreement between experimental measurements and model predictions is good. In vacuum, the wing experiences a superharmonic resonance when flapping at 1/3 its natural frequency due to periodic softening of this wing – this superharmonic response is attenuated in air due to fluid damping. We then use our model to study the influence of added mass when wing surface density is similar to that of a *Manduca sexta* wing. We show that, in addition to shifting the wing's natural frequency, added mass increases fluid loading on the wing by approximately 15%. The increased loading cannot be accounted for by adjusting the wing's natural frequency in simulation alone and must be treated as an independent forcing function. This work is an important first step towards developing FSI models that account for more realistic multiple degree-of-freedom flapping kinematics and complex wing geometries.

105-6 SCHWAHA, T; University of Vienna, Department of Integrative Zoology; *thomas.schwaha@univie.ac.at*
O anus where art thou? An investigation of ctenostome bryozoans
Defecation is a common process of removing undigestible food resources that can be quite copious in suspension feeders. In bryozoans the anus is situated outside of the food processing tentacle crown or lophophore. Bryozoans have a characteristic defensive behaviour that involves the retraction of their soft-body parts (the polypide) into their protective body wall (cystid). As colonial organisms, defecation represents an important task that requires and involves coordination to remove faecal pellets from the colony. This is particularly evident in species with closely spaced zooids. Among cheilostome bryozoans several different defaecation strategies have been recognized, whereas other bryozoans remain little investigated. Especially within ctenostome bryozoans, a small group of non-calcified bryozoans, the position of shows high variability concerning the location on the tentacle sheath. Some species have the anus situated very close to the mouth opening, which implies high interaction with feeding currents, whereas other have the anus located quite distant from the mouth opening. In any case, faecal pellets need to be removed from the colony. In this presentation I analyse the distribution of anal positions among ctenostomes and assess whether this position evolved independently and its consequences for colonial feeding currents.

131-3 SCHWANER, MJ*; FREYMILLER, GA; CLARK, RW; MCGOWAN, CP; University of Idaho, Moscow, ID, San Diego State University, San Diego, CA; *schw1900@vandals.uidaho.edu*
A heightened vigilance state alters mechanics of jump backs in kangaroo rats (D. deserti)
Predation pressures shape most animals' morphology and behavior. In the presence of a predator, animals have been shown to increase vigilance. Kangaroo rats, a bipedal hopping desert rodent, are known to exhibit a series of stereotyped anti-snake behaviors, such as head bobbing, foot drumming, and jump backs. During jump backs, animals make sudden jumps backwards without changing body or head orientation. These behaviors occur in response to predators, but also to novel objects. According to literature, in a vigilant state, kangaroo rats increase their performances; however, the difference in mechanics of these behaviors is less well studied. We hypothesized that kangaroo rats would respond faster, jump higher during jump backs, and perform more jump backs when experiencing a heightened vigilance state due to exposure to a predator. To test this, we collected data in the Mojave Desert (CA) using high-speed video examining jump height, take-off time, and number of jump backs by kangaroo rats that were in a heightened vigilance state after exposure to sidewinder rattlesnakes and individuals that did not see a snake before their encounter with a novel object. Comparing performance in both behavioral states showed that kangaroo rats in a state of higher vigilance performed more jump backs (4 - 9) in series and jump higher (0.10 – 0.26 m) compared to animals in less vigilant behavioral state (1 - 2 jumps in series, 0.06 – 0.18 m). That behavioral state can alter performance, suggests that laboratory studies might underestimate an animals' predator escape ability in the wild.

70-5 SCHWEIKERT, LE*; DAVIS, AL; JOHNSEN, S; BRACKEN-GRISSOM, HD; Florida International University, Duke University; *lorian.schweikert@gmail.com*

Vision and Bioluminescence in Deep-sea Shrimps: Implications for Conspecific Recognition

Bioluminescence is an important mediator of animal interaction in the deep sea. The forms and functions of bioluminescence are diverse, even among groups with shared evolutionary and ecological histories. In one such family of deep-sea shrimps, the Sergestidae ("*sergestes*" subgroup), light organs known as organs of Pesta have undergone species-specific diversification in morphology. However, the predicted function of these organs in counterillumination (a form of camouflage) has no obvious requirement for this variation, leading to the question: have light organs diversified across "*sergestes*" to serve as visual signals in conspecific recognition? Here, we examined different aspects of "*sergestes*" vision to assess their capacity to detect differences in their bioluminescent emissions. Selecting species with distinct organ morphologies (*Allosergestes sargassi*, *Parasergestes armatus*, and *Deosergestes henseni*), we examined eye to body size scaling relationships, as well as eye morphometrics for models of visual ability. Altogether, the conspecific recognition hypothesis was not supported. We found no sexual dimorphism in eye investment, which scales negatively with body growth across all species. Sighting distance models indicated relatively short distances (sergestes" vision, images of conspecific appearance rendered using 'AcuityView' software suggested the inability of these species to resolve variation in organ morphology. While bioluminescent patterns may not permit species discrimination, it may aid in localizing individuals over short distances; and thus, is capable of serving camouflage and visual signaling in this group, simultaneously.

54-1 SCHWEIZER, RM; JONES, MR; BRADBURD, GS; WOLF, CJ; SENNER, NR; STORZ, JF; CHEVIRON, ZA*; University of Montana, Michigan State University, University of South Carolina, University of Nebraska; *zac.cheviron@mso.umt.edu*

Genomic signatures of selection across the oxygen transport cascade in high-altitude deer mice

Evolutionary adaptation to novel environments often requires coordinated changes in independent physiological systems. For example, deer mice (Peromyscus maniculatus) that are native to high elevations in western North America differ from their low-elevation conspecifics in physiological traits that alter many steps in the oxygen transport cascade, and these changes are associated with improvements in aerobic performance under hypoxia. Here, we employed a population genomic approach to gain insight into the genetic basis of these adaptations. First, we sequenced the exomes of 100 mice sampled from low- and high-elevations to identify loci that bear the signatures of positive selection in highland mice. This analysis revealed 436 unique genes that have experienced a history of selection at high elevations, and these genes have functions that may affect each step of the oxygen transport cascade. Second, we performed geographic cline analyses using whole exomes from an additional 160 mice sampled from an elevational transect of the Rocky Mountains in Colorado. This analysis revealed that clines for outlier loci were centered at significantly higher elevations, and were wider, than those for random loci. This result suggests elevational patterns of allele frequency variation for outlier loci cannot be explained by neutral population structure. Together these analyses provide new insights into how natural selection acts to produce integrated adaptive phenotypes and the spatial scales over which this process occurs.

60-8 SCIBELLI, AE*; TRIMMER, BA; Tufts University, Department of Biology, Medford, MA, Tufts University; *anthony.scibelli@tufts.edu*

A bioinspired compressible soft robot for studying terrestrial crawling

Here we describe a bioinspired crawling soft robot that is capable of emulating the locomotion of soft-bodied insect larvae. The robot uses several design principles derived from neuromechanical studies of the caterpillar, *Manduca sexta*. 1) The body is made from light-weight open cell foam representing the compressible hemocoel of insect larvae. 2) Movement is produced using brushed DC motors that wind tendon-like cables. These generate active force in tension and the tendons are restored to their passive length by elastic recoil. This mechanical cycling resembles natural muscle work loops. 3) The tendons attach to a conformable mesh fabric surrounding the foam body. These attachments are similar to insect apodemes and they serve to distribute locally applied forces to large regions of the body. 4) The robot uses two modes of locomotion: crawling, produced by cycles of compression and extension, or whole body bending that resembles caterpillar "inching". This prototype is the first untethered terrestrial soft robot designed for real world applications such as environmental monitoring or search missions in unstructured, confined environments. For research purposes, several robot modules can be connected to more closely resemble the caterpillar body. This segmented robot could be used to test different motor control strategies and the role of sensory feedback in soft bodied crawling locomotion.

8-2 SCOTT-ELLISTON, A*; WARNE, R; Southern Illinois University, Carbondale, IL; *ayana.scott-elliston@siu.edu*

Modulation of the gut microbiome affects host developmental and stress response phenotypes

The capability of an organism to metabolize nutrients is crucial for fueling growth, facilitating development, and sustaining immune function, and variation in the gut microbiome during early life stages of an organism is often associated with altered host phenotypes and increased disease susceptibility. However, the biochemical mechanisms by which microbial communities affect an organism's health across ontogeny remain poorly understood. The Warne lab has recently demonstrated that in larval amphibians hatching constitutes a critical window for establishment of a gut microbiome, and gut bacterial diversity, specifically the ratio of Firmicutes to Bacteroidetes, influences development rate, growth, and mortality rate due to *Ranavirus* infection – an emerging disease for ectothermic vertebrates. Consequently, we tested how targeted manipulation of the gut microbiome and a prebiotic treatment can be used to modulate host development and stress response phenotypes. Through gut microbiome manipulation at hatching in these larval frogs and the subsequent prebiotic dietary treatment with a digestion resistant starch, we show that the gut microbiomial community structure affects growth, development, metabolism, and corticosterone responses to stress exposure. Specifically we found that (1) larvae with a disrupted gut microbiome exhibit significantly slower growth and development rates; while (2) disrupted larvae provided the starch experienced a rescue effect whereby they not only recovered growth rates compared to controls, but also exhibited significantly increased development rates; and (3) altered corticosterone responses to an external handling stressor. These results suggest gut microbiome and potentially metabolite profiles can be modulated to induce targeted effects on host function and health.

82-7 SEARS, MW*; NUSSEAR, KE; SIMANDLE, ET; Clemson University, University of Nevada, Reno; *thermalecology@gmail.com*
Biophysical ecology and the evolution of methods: are they deleterious mutations?
Ever since Cowles and Bogert demonstrated that reptiles could thermoregulate using behavior, investigators have developed various methods to show that these temperatures were not simply a passive response to the environment. Initially, sophisticated mathematical models calculated the energy balance of an animal at a specific point in time. Operative temperatures (T_es) from these calculations describe the instantaneous temperature for an animal given absorptive and convective properties, but with no heat capacitance. State of the art techniques were then developed, using hollow metallic replicas of animals, to approximate the T_es of individuals measured in real environments. When sampled over an environment, T_es can be used to benchmark thermoregulatory performance. Further, T_es can be used to calculate the body temperatures (T_bs) of individuals in a transient environment if additional information regarding thermal time constants are known. For various reasons, many biologists have substituted hollow metallic replicas with other types of inanimate objects, sometimes adding thermal mass to approximate a T_b rather than an T_e. In doing so, investigators have introduced errors into their work as their models have a substantial time lag, and are no longer taking direct measurements of T_e that could be used to examine thermal forcing in a changing environment or microhabitat (e.g. when thermoregulating). Here, we review the recent literature to 1) highlight the inappropriate measurement of T_es and its consequences, 2) suggest methodologies that might be able to correct some of these poor measurements, and 3) connect measurements of T_es back to the original underlying theory. Our hope is to clear up some fundamental misunderstandings of what T_es provide and to suggest future directions whereby correct measurements can advance our understandings of thermal biology.

49-6 SECOR, SM; University of Alabama; *ssecor@ua.edu*
Underlying Mechanisms that Drive an Adaptive Interplay in Digestive Physiology
Bill Karasov and Jared Diamond's 1988 article ‘Adaptive interplay between physiology and ecology in digestion' laid the foundation for my exploration in the adaptive interplay between feeding habits and the regulation of digestive performance. This work, largely undertaken with snakes, has identified an adaptive dichotomy for which frequently-feeding species narrowly regulate intestinal function with feeding, whereas species that naturally experience long periods between meals, due to an infrequent feeding behavior or dormancy, up and down regulate intestinal form and function with the start and finish of each meal. Proposed for why such a dichotomy exists resides in the energetic benefits of each mode as a function of feeding frequency. The cellular mechanisms underlying this dichotomy is apparently morphological, dictated by whether luminal surface area does not change with feeding or fasting (due to no change in microvillus length) as exhibited by frequent-feeders, or changes dramatically due to the postprandial lengthening of the microvilli and subsequent shortening following digestion as experienced by infrequent-feeders. Taking advantage of this dichotomy, our comparative approach is allowing us to identified specific gene programs and regulatory pathways responsible for the synthesis, mobilization and insertion of microvillus and membrane proteins involved in the postprandial remodeling of the brushborder membrane for infrequently feeding snakes. Given the convergent evolution of modes of regulatory responses among snakes, we are asking whether the underlying molecular programs of a common phenotypic response (i.e., microvillus lengthening) are conserved or have evolve independently, and thus are unique.

108-5 SEGRE, PS*; GOLDBOGEN, JA; Stanford University; *psegre@stanford.edu*
A computational framework for quantifying the maneuvering performance of free-swimming rorqual whales
Maneuverability, defined generally as the ability to change speed and direction, is critical to survival. Rorqual whales, the world's largest vertebrates, survive by catching much smaller and more maneuverable prey. They do so by using a series of surprisingly acrobatic maneuvers to approach schools of small fish or krill, accelerating, and engulfing large mouthfuls of prey-laden water. It has been thought that organisms that use lift based propulsion are constrained by the differential scaling of lift producing surfaces and body volume, but this has not been comprehensively tested in free-swimming animals. Rorqual whales exhibit a large range of sizes and have substantial differences in the morphology of body shape and propulsive surfaces, which makes them excellent subjects for studying the scaling of maneuvering performance at the upper extremes of body size. Using a collection of data from suction-cup attached, bio-logging tags equipped with a suite of inertial sensors (6 species, 384 deployments), we developed a framework to comprehensively quantify and compare the maneuvering performance of free-swimming whales. We identified five simple rotational and translational maneuvers (rolls, upward pitch changes, downward pitch changes, yawing turns, accelerations) that are effected by different hydrodynamic controls and can be sequentially pieced together to build complex trajectories used for capturing prey. Each type of maneuver is stereotypical, repeatable, and used thousands of times during the course of a multi-hour deployment, and thus can be automatically detected using a targeted search sequence. Taken together, an analysis of the performance limits of these five simple maneuvers and an analysis of how simple maneuvers are sequentially used to perform complex behaviors will allow us to quantify the overall maneuvering performance within and across species of rorqual whales.

50-2 SELLERS, KC*; MIDDLETON, KM; HOLLIDAY, CM; University of Missouri; *kcsty5@mail.missouri.edu*
Joint Loading and Transformation in Suchian Evolution
Modern crocodylians employ immense forces during feeding. Many characters that enable crocodylians to generate and resist these forces are not found in their ancestors, and thus the evolution of crocodylians involved a substantial reorganization of the feeding apparatus. Once this suite of changes was in place, crocodyliforms radiated into forms with derived diets and craniodental modifications. To assess the biomechanical effects of changing configurations of muscles and cranial joints, we used CT data to create 3D models of extant and fossil suchians that demonstrate the evolution of the crocodylian skull, using osteological correlates to reconstruct muscles. Muscle forces were distributed with the computational package Boneload and used as input for finite element analysis and 3D lever analyses. We found that jaw muscles expanded and shifted attachments throughout suchian 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. Changes to cranial joints accompanied muscular changes: the pterygoid buttress expanded, the articular surfaces of the jaw joint changed, and the quadrate and palate sutured to the braincase. Our results showed that joint force orientation tracks with articular surface metrics. We found that as bite location moves caudally, working side joint force decreases in magnitude; it is likely that in feeding events such as shaking bites or death roll, the jaw joint is loaded in tension. This study depicts a feeding apparatus that defies traditional understanding. The combination of dual craniomandibular joints and jaw joints loaded in tension is unknown from the rest of tetrapods.

27-8 SENEVIRATHNE, G*; BAUMGART, S; SHUBIN, N; HANKEN, J; SHUBIN, NH; University of Chicago, Chicago, Laboratory Schools, Chicago, Museum of Comparative Zoology and Harvard University, Cambridge; *gsenevirathne@uchicago.edu*
Ontogeny of the anuran urostyle: the developmental context of evolutionary novelty
Unique developmental novelties often mark evolutionary origins of metazoan structures. The anuran urostyle is one such structure. It forms during metamorphosis, as the tail regresses and locomotion changes from an axial-driven mode in larvae to a limb-driven one in adult frogs. Histologically, the urostyle comprises of a mesoderm-derived coccyx and an endoderm-derived hypochord. The coccyx is formed by the fusion of rudimentary caudal vertebrae. Across vertebrates, coccygeal fusions have repeatedly evolved with the loss of the tail. However, the contribution of an endoderm-derived ossifying hypochord to the coccyx in anurans is unique among vertebrates and remains a developmental enigma. Here, we focus on the developmental changes across ontogeny, leading to the anuran urostyle with an emphasis on the ossifying hypochord. We found that thyroid hormone directly affects hypochord formation but not the coccyx. The coccyx development is initiated before the metamorphic climax and depicts an endochondral ossification pattern, whereas the ossifying hypochord undergoes rapid ossification at metamorphic climax and shows hypertrophy. The embryonic hypochord is known to play a significant role in the positioning of the dorsal aorta (DA), but the reason to form an ossifying hypochord during metamorphosis has remained obscure. Interestingly, our results suggest that the ossifying hypochord also plays a role in re-arrangement of the DA in the newly forming adult body by partially occluding the DA in the tail, which subsequently regresses. We propose that the ossifying hypochord induced loss of tail during metamorphosis enabled the evolution of the unique anuran *bauplan*.

135-3 SEROY, SK*; GRUNBAUM, D; PADILLA, DK; University of Washington, Stony Brook University; *sseroy@uw.edu*
Inducible morphology reveals adult dispersal between habitats
The marine snail, *Lacuna vincta*, is an ecologically dominant grazer in kelp and eelgrass habitats. *L. vincta* exhibits inducible radula morphology dependent on current habitat, producing pointed teeth in kelp beds and blunt teeth in eelgrass beds. *L. vincta* adults disperse between these habitats via drifting on currents to avoid predation and to exploit seasonal shifts in resources. But dispersal behavior can result in arrival in a habitat that does not match a snail's radula morphology. Therefore, because this inducible morphology records individuals' histories of dispersal between these two habitat types, we used the interaction between individual-level plasticity and migratory behaviors to determine population-level characteristics of this important grazer in seasonal habitats. We surveyed two eelgrass and two kelp sites around San Juan Island, WA to assess radula mismatch and characterized flow regimes as a possible control on dispersal using novel micropython-based current speed sensors. Snails were collected during low tides from June to August 2019, dissected to extract the radula, and classified as matched, transitioning or mismatched to their current habitat. In eelgrass beds, proportions of matched snails increased over the summer, potentially reflecting the seasonal availability of eelgrass epiphytes and suggesting snail retention at these sites. In kelp beds, proportions of matched snails decreased over the summer, indicating potential high migration to and from these sites. Kelp sites had slower flow regimes than eelgrass sites. Preliminary analysis suggests a positive relationship between flow speed and radula mismatch at kelp sites, with a weaker effect at eelgrass sites. Our work shows how inducible traits can be used to quantify interactions between organism- and habitat-level ecological mechanisms in marine environments.

65-7 SETH, D; Villanova University; *deeksha.seth@villanova.edu*
Development of an Interactive Model of a Snake Jaw for Natural and Applied Science Education
Multi-disciplinary education has become a critical part of formal and informal curricula to teach students how different disciplines work in harmony and to provide an exciting experience that can encourage the students to pursue education and careers in the science, technology, engineering and mathematics (STEM) fields. Due to the popularity of biomimicry, the integration of biology and applied sciences is becoming increasingly visible in curricula throughout the country, especially in museums where animal-related behaviors are popular. Recognizing the need for interactive tools that can make the integrated STEM education fun and effective, the objective of this work was to develop a biologically accurate model of a snake jaw that can demonstrate the function of the quadrate bone and how the unique physiology contributes to the large range of motion in the jaw. The goal of this model was also to teach other integrated STEM topics, such as mathematics. The robotic snake jaw was developed at Villanova University as a part of the undergraduate capstone program. The model uses servo motors that are individually controlled using an Arduino board. The frame and exterior skull of the device was modeled using SolidWorks and 3D printed. The device consists of movable inner and outer, lower and upper mandibles of the jaw as well the unique quadrate bone. Lastly, the device has a pre-programmed motion to simulate a human jaw movement to show the audience the effect of the quadrate bone on the range of motion. The device also enables teaching simple algebraic relations and advanced geometric and trigonometric relations for an interactive mathematics session. The device is currently housed at The Academy of Natural Sciences of Drexel University. In the upcoming months the device will be assessed.

62-1 SETH, D*; LAUDER, GV; FLAMMANG, BE; TANGORRA, JL; Villanova University, Harvard University, New Jersey Institute of Technology, Drexel University; *deeksha.seth@villanova.edu*
Fish Fin Compliance: A Perturbation Technique to Determine Compliance During Free Swimming
Despite significant importance, compliance of fish fins has not yet been investigated with live, freely-swimming fish. This is partly due to the challenges of interrogating a live fish during free swimming and the lack of adequate experimental devices and methodologies to measure the stiffness of the fin. The objective of this work was to validate a perturbation technique by predicting a known change in the stiffness of a physical system. A physical model of known stiffness was built and perturbed with a vortex ring, and its response was measured using high speed video. A second-order model was used to predict how the response of the system changes with compliance and those changes were compared to those observed experimentally. Comparison of the predicted and measured responses suggested that the displacement and the rate of displacement from unperturbed state can be enough to assess the compliance change. For the technique to be applicable to a fish, changes in displacement in the initial 20 – 100 ms due to a change in compliance were compared. This was done to ensure that the technique can work on the live fish by only looking at the passive response in the fin. The proposed technique of applying a known force to the fin and predicting compliance changes by looking at the displacement in the fin, was successful in estimating a known compliance change in a physical system. As the stiffness increases, the displacement at a given time can be expected to decrease and the rate of change from unperturbed state to that displacement at a given time can be also be expected to decrease. These trends hold true within 20 – 100 ms. Future work will involve studying the interaction of the vortex ring with flexible structures under water, so the force estimate of the vortex ring can be better validated for the biological studies.

46-3 SETTON, EVW*; SHARMA, PP; University of Wisconsin - Madison; *setton@wisc.edu*

The fly cannot save us: Using developmental transcriptomes to probe the genetic architecture of spider spinnerets

The phylum Arthropoda is a formidable system for understanding the developmental genetics of novel structures, with an abundance of structural innovations across the diversity of this group. Candidate gene approaches, grounded in established insect models like the fruit fly *Drosophila melanogaster*, have helped answer questions about some novelties, such as insect wings. This approach, however, is not suitable for study of evolutionary novelties that are restricted to distantly related lineages and is thus inadequate for probing the genetic architecture of structures not found in *D. melanogaster* or its close relatives. One such structure is the web-weaving organ of spiders, the spinnerets. Here we offer an alternative to the insect-based candidate gene approach toward a more comprehensive understanding of spinneret genetic architecture. We utilized appendage-specific transcriptomes of nascent spinnerets in the tarantula *Aphonopelma hentzi* and applied differential gene expression (DGE) analyses to derive a list of candidate genes specific to spinneret primordia. Here we share preliminary data for genes identified as highly differentially expressed in the developing spinnerets compared to primordial legs. We also examine leg and spinneret genes' ages using a phylostratigraphic approach as a test of evolvability. More broadly, our novel application of transcriptomic data and DGE analyses opens the door to identifying genes putatively important in the specification of other appendages types found exclusively in lineages distantly related to insects.

55-1 SEWALL, KB*; DAVIES, S; BECK, ML; Virginia Tech, Quinnipiac University, Rivier University; *ksewall@vt.edu*

Relationships Among Neuropeptides, Territorial Aggression, and Urbanization in Male Song Sparrows

Urbanization is a critical form of environmental change that can affect the physiology and behavior of wild animals and, notably, birds. One behavioral difference between birds living in urban and rural habitats is that urban males show elevated territorial aggression in response to simulated social challenge. This pattern has been described in several populations of song sparrow, *Melospiza melodia*. Such behavioral differences must be underpinned by differences in the brain, yet little work has explored how urbanization and neural function may be interrelated. Our previous work compared a marker of neural activation in response to song playback (the immediate early gene FOS) and expression of a neuropeptide involved in territorial aggression, arginine vasotocin (AVT), within nodes of the brain social behavior network of urban and rural male song sparrows. This initial work implicated both FOS expression and AVT in mediating behavioral adjustments to urbanization in male song sparrows. However, we were unable to correlate these brain measures with birds' territorial responses. In the present study we again compared FOS and AVT immunoreactivity within nodes of the social behavior network from urban and rural males but also correlated these measures of male territorial aggression and quantified co-localized protein expression. This approach allowed us to determine if neuropeptide expressing neurons were activated during elevated aggressive responses. Our findings implicate neural activation of neuropeptide-expression cells within the social behavior network of the brain in regulating the well-established differences in territorial behavior among song sparrows living in rural and urban habitats. We discuss how changes in neuropeptide systems could underpin both facultative and evolutionary adaptation to urban habitats.

26-4 SHANKAR, A*; MCCAHON, S; CALLEGARI, K; SEITZ, T; DROWN, D; WILLIAMS, CT; University of Alaska Fairbanks; *nushiamme@gmail.com*

SAD rats: Effects of short photoperiod on sleep disruption, the gut microbiome, and carbohydrate consumption in diurnal grass rats

Seasonal affective disorder (SAD) is a recurrent depression triggered by short photoperiod exposure. In addition to being a major mental health issue, SAD has been linked to circadian dysfunction and weight gain, both of which have important implications for susceptibility to cardiovascular disease, type II diabetes, and metabolic syndrome. We use a diurnal rodent model, the Nile grass rat (*Arvicanthis niloticus*), to examine the effect of photoperiod (short 4:20 LD vs. neutral 12:12 LD) on sleep and activity patterns, sucrose consumption, and gut microbiome changes. We tracked individual sleep patterns in 45 grass rats and assessed reward-seeking behavior by measuring their consumption of high-concentration (8%) sucrose (HCS) solution. We collected liver (to diagnose fatty liver disease), cecum, large intestine, and periodic fecal samples (to characterize the diversity and functional profile of the gut microbiome). We found that animals on short photoperiods showed disrupted activity and sleep patterns, but maintained strong diurnal rhythms and similar subjective day lengths. We found no effect of photoperiod on sucrose consumption, but short photoperiod individuals had marginally higher liver fat content, and those with access to high sucrose had higher liver fat across both photoperiod treatments. Our study highlights the potential for metabolic effects of exposure to short photoperiods. Completion of sequencing will allow us to assess whether these effects are associated with shifts in the gut microbiome diversity or functional profile.

S7-6 SHARBROUGH, J*; MONTOOTH, K; NEIMAN, M; Colorado State University, University of Nebraska, University of Iowa; *jsharbro@colostate.edu*

Phenotypic Variation in Mitochondrial Function across New Zealand Snail Populations

Mitochondrial function is critical for energy homeostasis and should thus shape how genetic variation in metabolism is transmitted through levels of biological organization to generate stability in organismal performance. Mitochondrial function is encoded by genes in two distinct and separately inherited genomes, and selection to maintain mitonuclear interactions is often intense. The frequently observed high levels of polymorphism in genes involved in mitonuclear interactions and variation for mitochondrial function is thus surprising and demands explanation. *Potamopyrgus antipodarum*, a New Zealand snail with coexisting sexual and asexual individuals and, accordingly, contrasting systems of separate vs. co-inheritance of nuclear and mitochondrial genomes, provides a powerful means to dissect the evolutionary and functional consequences of mitonuclear variation. The lakes inhabited by *P. antipodarum* span wide environmental gradients, with substantial across-lake genetic structure and mitonuclear discordance. We can therefore make comparisons across reproductive modes and lakes to partition variation in cellular respiration across genetic and environmental axes. Here, we integrated cellular, physiological, and behavioral approaches to quantify variation in mitochondrial function across wild P. antipodarum lineages. We found extensive across-lake variation in organismal oxygen consumption and behavioral response to heat stress, coupled with elevated mitochondrial membrane potential in males. These data set the stage for applying this important model system for sex and polyploidy to dissect the relationship between mitonuclear variation, performance, plasticity, and fitness in natural populations.

64-3 SHARMA, VP*; SPONBERG, SN; Georgia Institute of Technology; *vsharma98@gatech.edu*

Context Dependent Sensing and Robust Integration of Visual and Mechanosensory Stimuli in Hover-Feeding Hawk Moths

Insects exhibit robust goal-tracking behavior in a range of environmental conditions. In the presence of redundant, parallel sensory information, how does multimodal integration depend on environmental conditions, such as light-level? *Manduca sexta* (tobacco hawk moths) hover-feed under conditions ranging from moonlit nights (0.3 lux) to early twilight (300 lux). From earlier work on hover-feeding hawk moths at 0.3 lux, we know that mechanical and visual cues sum linearly in tracking, but mechanosensory gain is higher for slow movements and visual gain is higher for fast movements, an example of bandwidth separation. Visual processing delays depend on light level. Whether this bandwidth separation and linear integration remain true under high illuminance, or changes to accommodate the more salient visual inputs, was unknown. Hence, we studied hover-feeding behavior of *Manduca sexta* under high illuminance conditions (300 lux). Mechanical cues (to the proboscis) and visual cues (to the eyes) were provided, together and in conflict, using a two-part robotic flower. Frequency-domain system identification analysis showed that the high visual gain shifts the frequency crossover point between mechanical and visual modalities to lower frequencies. Nonetheless, the linear sum of the two conflict-responses matches the response to coherent flower motion. Hence, linearity is conserved irrespective of illuminance level, and the internal gain of visual cues is enhanced in the presence of a more salient visual environment. Parallel sensory inputs are modulated to achieve performance requirements, while maintaining linearity of the resulting behavior. This suggests that the underlying neural circuits are flexible, accommodating variable delays and sensitivity as light level changes, and robust in their integration.

59-8 SHARMA, PP*; ARANGO, CP; BALLESTEROS, JA; BRENNEIS, G; DILLY, GF; SETTON, EVW; WHEELER, WC; University of Wisconsin-Madison, Queensland Museum, University of Greifswald, California State University-Channel Islands, American Museum of Natural History; *prashant.sharma@wisc.edu*

Phylogenomic resolution of sea spider relationships via integration of phylogenetic data classes

Pycnogonida (sea spiders) is a fascinating group of marine arthropods renowned for their bizarre appearance and the widespread trait of exclusive paternal care of egg masses. The sister group to the remaining Chelicerata, the ca. 1350 known species of this lineage have an ancient origin, with crown-group body fossils present in the Silurian. However, higher-level phylogenetic relationships of sea spiders remain poorly understood, which has hindered inferences of morphological and developmental evolution, as well as estimation of divergence times. Previous efforts to infer the phylogenetic relationships of sea spiders have been hindered by the low informativeness of some Sanger-sequenced markers, the rarity of species in small-bodied families, and the pervasiveness of missing data in molecular phylogenetic matrices. To overcome these hurdles, we devised a phylogenomic approach to inferring sea spider relationships, capitalizing upon museum collections and sorted material from benthic surveys. Our sequencing strategy aimed to integrate several data classes, namely, ultraconserved elements, targeted exons, and mitochondrial genomes. Here, we show that integration of these data classes results in a robustly resolved basal phylogeny of sea spiders, with high nodal support for interfamilial relationships. We infer the age of crown-group Pycnogonida for the first time using internal fossil calibrations in a Bayesian inference framework. Finally, upon this temporal context, we contrast the different data partitions to identify which are the most informative for resolving relationships of varying phylogenetic depths.

43-4 SHARPE, SL*; UNGERER, MC; NIPPERT, JB; Kansas State University; *sharpes@ksu.edu*

Effects of Abiotic Stress Across Population in Wild Foxtail Millet Setaria viridis

BACKGROUND/QUESTION/METHODS Abiotic sources of stress, including drought, cold, and salinity, can substantially affect plant fitness and survival. This poses a significant threat to conservation, economic activities, and agriculture as climate change increases the stochasticity of temperature, precipitation, and availability of fresh water. Stress tolerance can vary widely between species and across differently adapted populations within a species. Environmental stress can decrease photosynthesis, diminish vegetative growth, and reduce reproductive allocation, each of which has serious consequences for agricultural and bio-energy crops. This research examines physiological and transcriptomic responses to abiotic stress across populations in the wild foxtail millet, *Setaria viridis*, a close relative of the agriculturally important foxtail millet, *Setaria italica*. We assessed differences in response to cold, drought, and salinity stress between two populations of *S. viridis* (one from China and one from Chile) in controlled greenhouse and cold room environments. RESULTS/CONCLUSIONS Physiological responses to drought stress, measured by photosynthetic rate, differed significantly between populations. Preliminary results indicate that plant response to cold stress at -5 degrees Celsius did not differ based on prior cold acclimation or population. We are awaiting sequencing data which will allow us to compare transcriptomic and phenotypic responses by quantifying up and down regulation of genes across treatment and population. Gene ontology analyses will be used to determine the function of genes that are significantly up or down regulated between groups. Ultimately, this research will help elucidate effects of population adaptation on abiotic stress response in a close relative of an important agricultural crop.

16-7 SHARPE, SL; Kansas State University; *sharpes@ksu.edu*

Creating LGBTQIA+ Inclusive Biology Curricula and Classrooms

LGBTQIA+ students in college biology classes often find their identities and experiences ignored or stigmatized, which can alienate these students from continuing to study biology and reaffirm harmful misconceptions about sex, gender, and sexuality for both these students and their heterosexual, cisgender peers. On a political and cultural level, the stigmatization and invalidation of queer, transgender, and intersex identities is often justified by appeals to the supposed biological immutability of sex binaries and the utility of heterosexual reproductive pairings. As scientists and educators, we have the opportunity to increase the inclusivity of our research, classrooms, and curricula by challenging these misconceptions while incorporating and exploring the diversity and complexity of sex, gender, and sexuality in human biology and across taxa. By developing intentional and inclusive biology classrooms and curricula, we can instill in our students 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 on sex, gender, and sexuality across taxa.

44-1 SHIELDS-ESTRADA, AK*; CANNATELLA, DC; University of Texas at Austin; *ashieldsestrada@utexas.edu*

Near Infrared Reflectance & Thermoregulation in Epipedobates Poison Frogs

Adaptive variation in color reflects a suite of organismal specific traits and behaviors, ranging from warning signaling to thermoregulation. However, how this variation is partitioned within the spectrum of solar radiation (300-2500nm) and why, remains unknown. The near-infrared reflectance (NIR) spectrum (700-2500nm) compromises 55% of all solar irradiance, yet spectral reflectance is rarely measured outside of the UV or visible spectra. Furthermore, extensive animal insensitivity to near-infrared wavelengths, makes this spectrum an ideal candidate for understanding the role spectral reflectance plays in ectotherm thermal physiology. The NIR spectrum may be less constrained by selection for warning signaling, camouflage, and sexual signaling, and may instead largely reflect thermoregulatory requirements. Our work examines the relationship between NIR, visible spectral reflectance, and thermoregulation, in a clade of Epipedobates poison frogs exhibiting a diverse range of color variation and thermal habitat regimes. We measured spectral reflectance of cryptic and conspicuous species throughout western Ecuador across elevational and temperature gradients in both the visible and NIR spectra (400-1100nm), and measured critical thermal maxima & minima (CTmax & CTmin), desiccation rate, and body temperature of each individual. Our results show statistically significant differences between total reflectance in the NIR spectrum and the visible spectrum, indicating the possibility of different selective pressures on each spectrum, and emphasizing the need to consider multiple spectra when studying adaptive variation in color. Furthermore, we found inter-populational variation in CTmax, CTmin, desiccation rate, and body temperature that may illuminate NIR's role in thermoregulation.

68-5 SHORE, A*; SANDERS, K; CONETTA, D; CORREA, AMS; Rice University; *ashore@rice.edu*

Hypoxia and coral microbiomes: Linking field and experimental data

Reduction of dissolved oxygen (DO) in ocean surface waters is a consequence of both local (eutrophication) and global (ocean warming) stressors. Recently, acute conditions of low DO have been linked to mass mortality events on coral reefs. Few studies have investigated the impact of low DO events on coral microbiomes, which are important in coral health and tolerance to environmental stress. We present one of the first studies to examine coral microbiome responses to low DO, coupling field and lab results. In July 2016, benthic organisms on reefs at the Flower Garden Banks National Marine Sanctuary (FGBNMS, northwest Gulf of Mexico) experienced a Localized Mortality Event (LME), which was linked to encroachment of storm-generated floodwaters, up-welling, and low DO. We collected healthy and dying corals (*Orbicella faveolata*) and other dying organisms at the FGBNMS during the LME and during the next corresponding season with 'normal' conditions (approximately two years after the LME). Many abiotic and biotic factors change when floodwaters interact with reef environments, making it difficult to disentangle the effects of low DO from co-occurring stressors. To further examine the immediate responses of *O. faveolata* to low DO in the absence of other stressors, we experimentally reduced DO directly (bubbling with N_2 gas) and indirectly (limiting gas exchange with the atmosphere). We then characterized coral-associated bacterial communities from field and experimental samples, and compared the long-term response of corals collected from the FGBNMS to the short-term response seen in experiments. A better understanding of the resiliency of reef-building corals to low DO is important given the significant threat of ocean deoxygenation.

94-3 SHORT, RA*; LAWING, AM; Texas A&M University, College Station; *rachel.a.short@tamu.edu*

Locomotor morphology of ungulate communities as an environmental predictor

Ecometric methods capture functional trait-environment relationships at the community-level and can be applied to fossil and future assemblages to understand change through time. We developed an ecometric model using the calcaneal gear ratio of ungulates across the globe. The gear ratio is a measurement of the overall length of the calcaneum divided by the length of the in-lever, i.e. calcaneal tuber. A low gear ratio indicates a long in-lever and a more plantigrade stance, e.g. pygmy hippo, whereas a high gear ratio indicates a short in-lever and a more unguligrade stance, e.g. steenbok. We tested the hypothesis that communities exhibiting higher gear ratios tend to occur in hot, dry, open habitats, whereas communities exhibiting lower gear ratios occur in cool, wet, closed habitats. We sampled ungulate species composition, mean and standard deviation of gear ratio, and environmental variables, including temperature, precipitation, and vegetation cover, at 50 km equidistant points across the globe (180 species and 53922 points). To discern relationships between morphology and environment, we calculated the most likely environment given community values of gear ratio. Anomalies between the observed and estimated values were used to evaluate ecometric models. For logged precipitation, anomalies ranged between 3.98 and -5.39 mm. With this ecometric framework, fossils of ungulate postcrania can be used to interpret paleoenvironment for a more comprehensive understanding of the past. These relationships between community morphology and environment will enable better models of biotic responses for conservation under changing environments.

76-6 SIDDALL, RJD*; JUSUFI, A; Max Planck Institute for Intelligent Systems; *rob@is.mpg.de*

Modulation of Cranio-Caudal mass distribution facilitates obstacle traversal in a cursorial biorobotic model

From the long necks of giraffes and hyenas, to the large tails of crocodilians, terrestrial animals display a broad diversity of body plans. Additionally, ecological situations such as the carrying of prey, caudal autotomy, offspring, undigested food, or pregnancy will each affect the distribution of mass. We seek to gain insight into how animals may use cranio-caudal mass redistribution to reject disturbances as they navigate uneven terrain. To do so, we have performed experiments using a robophysical model with adjustable mass distribution. In our biorobotic experiment, weights equal to 10% total mass are placed on elastic suspensions at varying distances, simulating the effect of 'head' or 'tail'-biased mass distribution. The performance of the robot traversing an obstacle is then recorded in a variety of configurations, including both legged locomotion with compliant whegs, highly damped airless tires, and wheels. The accumulated results of 126 trials indicate that massive passive tails (without ground contact) can have a destabilizing effect, while head mass enhances traction and suppresses perturbation in many cases. Based on this, the experiment is being expanded to appendages with an active response, moving mass and increasing inertia in response to sensing. Preliminary results from the pilot study suggest active modulation in anticipation of an obstacle, such as a hurdle, will control body attitude, resulting in reduction of undesired oscillations with respect to the cranio-caudal axis (body pitch). This study shows the advantages of mass redistribution in dynamic locomotion, and offers insight into the diversity of evolved body plans, and the use of robophysical models as instruments of discovery.

S2-6 SILVESTRE, F*; CARION, A; CHAPELLE, V; VOISIN, A-S; FELLOUS, A; SUAREZ-ULLOA, V; MARKAY, A; HETRU, J; GOUJON, V; WAUTHIER, E; CHATTERJEE, A; EARLEY, RL; University of Namur, Belgium, University of Otago, Dunedin, New Zealand, University of Alabama, Tuscaloosa, USA; *frederic.silvestre@unamur.be*

The Self-Fertilizing Mangrove Rivulus as a Model Species in Environmental Epigenetics

There is an increasing body of evidence that epigenetic variation can contribute to phenotypic changes in a population. A deeper understanding of the roles of epigenetics in phenotypic diversity and in organism adaptation and evolution can only be achieved in individuals that are genetically identical but naturally exhibit a range of heritable phenotypes. For that purpose, the mangrove rivulus, *Kryptolebias marmoratus*, is a precious model. Closely associated with red mangroves from Florida to South America, it shows numerous adaptations that facilitate survival in environments with considerable variability. Its main biological particularity is its mixed-mating reproductive system wherein hermaphrodites can either fertilize their own eggs or mate with males. Depending on the geographical region, the ratio between hermaphrodites and males varies alongside selfing rates, which directly affects genetic diversity. Here, we characterized DNA methylation in adults and during embryogenesis. Differentially methylated fragments were associated with specific behavioral traits such as boldness and aggressiveness. Effects of exposure to different environmental contaminants, such as neurotoxic compounds or endocrine disrupting chemicals were assessed to investigate relationships between DNA methylation and phenotypic variation. Collectively, our research has demonstrated extensive opportunity for epigenetic change during early life, which might underlie the diversity of phenotypes exhibited both within and among genotypes.

105-3 SIMON, MN*; BRANDT, R; KOHLSDORF, T; MARROIG, G; University of Sao Paulo; *monique.simon@usp.br*

Linking Phenotypic Modularity to Directional Selection on Multiple Functional Performances

A better comprehension of the evolution of complex multivariate phenotypes can be achieved by unravelling the factors that shape trait correlations and modularity. An underexplored question is how directional selection on multiple functions contributes to phenotypic modularity. We hypothesized that combinations of traits describing the pattern of trait modularity would be under directional selection associated with performance, reflecting potential functional trade-offs. We tested this hypothesis using the lizard *Tropidurus catalanensis*, for which four locomotor performances were measured - climbing, grasping, sprinting and exertion - and a trade-off between grasping and exertion was found. We estimated selection as linear performance gradients of hindlimb traits (bones and muscles) on the four performances, using original traits and eigenvectors of the phenotypic correlation matrix (P-matrix). We expected the same eigenvector to show significant performance gradients for grasping and exertion, but with opposing signs. We found that two eigenvectors of the P-matrix, allometric size and a contrast involving the thigh muscle, are under significant directional selection associated with grasping, sprinting and exertion. Also, allometric size shows opposing signs of performance gradient associated with grasping and exertion, indicating conflicting selection. However, the most apparent modular signal (bone x muscle contrast) was not under significant directional selection, but instead seems to match developmental processes. Our results indicate that directional selection on different performances can reduce or increase phenotypic modularity depending on which combinations of traits affects each performance.

113-6 SIMONITIS, LE*; MARSHALL, CD; Texas A&M University at Galveston, Texas A&M University at Galveston, Texas A&M University; *laureneve@tamu.edu*

A Natural Occurring Shark Repellent: Ink has a Negative Effect on Shark Swimming Behavior

Inking is an antipredator defense system which affects predators visually (as a smoke screen) and chemically (as a deterrent). As a chemical deterrent, ink is thought to either disrupt the reception of chemicals or act aversively to a predator's chemosensory systems. The use of ink as a defense is known for a variety of animals such as sea hares, cephalopods, and even whales. We hypothesized that ink acts as a chemical deterrent, negatively impacting the normal swimming behavior of bonnethead sharks. To determine how ink acts as a chemical deterrent, ink from California sea hares (*Aplysia californica*), common cuttlefish (*Sepia officinalis*) and pygmy sperm whales (*Kogia breviceps*) were introduced into the path of free swimming bonnethead sharks (*Sphyrna tiburo*). Sharks (n=7) were individually placed in a circular mesocosm with a GoPro camera mounted overhead. Locomotory kinematic variables (e.g. angular velocity, angle of deviation, seconds to max deviation, distance of max deviation, etc.) were recorded in response to each of the experimental treatments: the three inks, food odor (to test for a positive response), food coloring (to control for color), and sea water (to control for mechanosensory stimulation). Food odor provoked a significantly positive effect while all three inks elicited significant negative responses in at least one of the kinematic variables. These data confirm that ink negatively impacts shark swimming behavior. Future studies will address the ability of ink to deter a predation event, the chemical makeup of the ink, and the electrophysiological reaction of shark olfactory systems to ink.

36-6 SIMPSON, DY*; TELEMECO, R; LANGKILDE, T; SCHWARTZ, TS; Auburn University , California State University, Fresno, Pennsylvania State University; *dys0004@tigermail.auburn.edu*

Differential Gene Expression to heat or fire ant envenomation in Sceloporus undulatus

Environmental stressors can negatively affect an organism's performance, survival, growth rate, and ultimately its fitness. The underlying molecular mechanisms of how organisms respond to diverse stressors are still poorly understood. *Sceloporus undulatus*, the eastern fence lizard, has become an ecological model organism for addressing questions in ecology, and life history evolution. We have developed a high-quality reference genome that furthers the utility for investigating molecular and physiological mechanisms. We are interested in understanding how stress responses may vary when an organism is exposed to diverse environmental stressors such as an extreme heat event as predicted by climate change, or attack by an invasive predator such as a fire ant. In this study we test whether stress response to either acute heat or fire ant attack diverges at the endocrine level (plasma corticosterone levels) or at the gene expression level. We found that male *S. undulatus* (n = 24) who were either exposed to heat (43C) for up to 3 hours or fire ant envenomation (receiving ~10 stings) each had the same response in corticosterone levels, with an increase relative to the control. Liver RNA seq data are being analyzed to test whether the gene expression response to acute heat and fire ant envenomation is also highly similar or is divergent. These results will bring further insight into the similarity of molecular responses to ecologically relevant stressors.

S4-4 SIROT, L.K.; The College of Wooster; *lsirot@wooster.edu*
Opportunities for Female Modulation of Seminal Fluid Molecules
In many animal species, seminal fluid molecules (SFMs) influence female post-mating processes that affect reproductive success. SFMs have been most thoroughly studied in insects in which the affected processes include: egg development, sperm use, mating behavior, attractiveness, and lifespan. The magnitude of the effects of SFMs can be quite variable, even within inbred strains. This variation is important because it could impact post-copulatory reproductive outcomes. One likely cause of this variation is modulation by males or females of the quantities or qualities (e.g., stability or activity state) of SFMs, or, in the case of females, of their sensitivity to SFMs. Here, I review opportunities for SFM modulation by males and females, with a special emphasis on providing a framework for understanding the stages at which there is evidence for female control of the effects of SFMs. These stages occur during, after, and in between copulations and include behavioral, physiological, and biochemical mechanisms. I propose that these processes could provide mechanisms by which information received before and during copulation influences post-copulatory reproductive success and suggest ideas for future research in this area.

43-1 SIROVY, KA*; KELLY, MW; JOHNSON, KM; Louisiana State University; *ksirov1@lsu.edu*
Intraspecific variation in the stress response of the Eastern Oyster, Crassostrea virginica, to salinity changes within the northern Gulf of Mexico
Anthropogenic activity is rapidly shifting environmental variables, causing an urgent need to understand how organisms will respond to changing conditions. This is especially important for oysters as they provide essential ecosystem services including water filtration, shoreline stabilization, and habitat for other marine invertebrates. Within the northern Gulf of Mexico, salinity is one of the most important variables impacting *Crassostrea virginica* and is expected to change rapidly over the coming century. Our objective is to improve our understanding of how the eastern oyster will respond to salinity changes by addressing a major gap concerning the potential for local adaptation to drive differential stress responses across populations. Specifically, we will focus on the role of gene expression changes because shifts in gene expression across populations are often crucial for adaptation to an environmental change. To approach this objective, adult oysters were collected from two sites in Louisiana which naturally differ in their salinity regimes. These oysters were placed in common garden conditions, spawned, and the resulting juveniles were outplanted to either a high or low salinity site. After 15 months of exposure, TagSeq was used to measure the gene expression of juveniles from both treatments. We expect that at both sites there will be differentially expressed genes between individuals with different parental origins representing localized responses to salinity stress. We expect this to be most noticeable at the low salinity site, as this represents the most stressful condition. Differentially expressed genes can provide insight into mechanisms underlying population differences in the physiological response to salinity stress.

24-5 SLAMA, SL*; SANDMEIER, FC; SHEEDY, MD; PAINTER, MN; Colorado State University Pueblo; *sadelbush@gmail.com*
Quantifying Phagocytic Activity of Lymphocytes in Ectotherms
We used blood samples from Mojave desert tortoises (*Gopherus agassizii*) to show that phagocytosis by lymphocytes occurs at a high but variable rate among individuals and can be quantified with and without species-specific reagents. Thus, this is an important new measure to add to the toolbox of ecological immunologists who are working with species of ectothermic vertebrates. Phagocytosis is an important aspect of innate immunity in which foreign elements are recognized by immune cells via receptors and are internalized, thereby clearing the body of potentially harmful pathogens. While lymphocytes are known to serve key functions within adaptive immunity, these cells have been previously shown to perform the innate immune function of phagocytosis in a wide variety of ectothermic vertebrates. These past studies have all relied on both expensive machinery and species-specific reagents. We optimized phagocytic assays for use in desert tortoises, using published protocols, species-specific reagents, fluorescent and confocal microscopy, and flow cytometry to verify and distinguish between innate binding of beads and true phagocytosis. However, we also show that simple Wright-Giemsa staining can be used to quantify binding and phagocytosis. Therefore, we show that this technique is widely applicable, with the recognition that some optimization-steps will need to be adjusted for use in different taxa. We offer suggestions for trouble-shooting optimization steps and hope to establish this technique as a common tool to assess immune function across species of ectothermic vertebrates.

14-5 SLEBODA, DA*; WOLD, ES; ROBERTS, TJ; Brown University, Providence, RI; *david_sleboda@brown.edu*
The Hydrostatic Skeleton of Muscle
Fluid accounts for over 70% of muscle mass, filling intracellular, extracellular, and capillary spaces. During normal physiological activity intramuscular fluid pressures develop as muscle exerts a portion of its developed force internally. These pressures, typically ranging between 10 and 250 mmHg, have the potential to influence force and work produced during contraction. Classic Hill-type models of muscle rarely incorporate fluid into their designs. Here we test a model of muscle structure in which intramuscular pressure directly influences muscle mechanics. Using a pneumatic cuff, we pressurized isolated bullfrog muscle mid-contraction at 5 psi (~260 mmHg) and measured the effect on isometric force. We compared the response of muscle to that of a simple physical model of muscle fiber and extracellular matrix morphology. Experimentally pressurizing isolated bullfrog muscle reduced isometric force at short muscle lengths (e.g. -11.87% of P_0 at 0.9 L_0), increased force at long lengths (e.g. +3.08% of P_0 at 1.25 L_0) but had no effect at intermediate lengths ~1.10-1.15 L_0. Our physical model qualitatively mimics this variable response, displaying negative, positive, or neutral responses to pressurization depending on the orientation of reinforcing fibers representing extracellular matrix collagen. Our findings show that pressurization can have immediate, significant effects on muscle contractile force and suggest that forces transmitted to the extracellular matrix via pressurized fluid may be important, but largely unacknowledged, determinants of muscle performance *in vivo*. The work draws parallels between muscle and the hydrostatic skeletons typical of soft-bodied animals and plants, and exemplifies the importance of emergent, multiscale mechanics in biological systems.

8-7 SLEVIN, MC*; FRESIN, W; CANNATARO, G; ANDERSON, RC; Florida Atlantic University; *mslevin2018@fau.edu*

Smarts and Symbiosis: Elucidating the Relationship between the Microbiome and Cognitive Performance in Birds

Recent years have seen a surge of research on the link between an individual's cognitive ability and its gut microbiome. With recent advances in understanding avian cognition, songbirds are an ideal system for investigating this relationship. In a captive Zebra Finch (*Taeniopygia guttata*) population of 42 adults, I quantified individual variation in performance on cognitive tasks (novel foraging, color association, and color reversal) that measure motor learning and memory, recording the number of trials needed to pass each task and error rate per trial. I sampled the gut microbiome via cloacal swab immediately prior to testing, sequenced the bacterial taxa present, and assessed diversity and relative abundance in each sample using Qiime2. There was high individual variation in cognitive performance, ranging from 22 to 80 trials needed to complete all three tasks (mean = 15.1 ± 1.4 trials for novel foraging, 9.4 ± 0.8 for color association, and 16.2 ± 0.9 for color reversal), with no sex difference for any task (all $P > 0.18$). Color association and reversal performance were correlated ($r = 0.3$, $P = 0.03$), but neither task was correlated with novel foraging performance ($r = -0.02$, $P = 0.9$). Finally, the slope of the per-trial error rate over the course of each color task was significantly correlated with the number of trials needed to complete the task ($r = 0.4$, $P = 0.003$). I will relate each bird's cognitive performance to its microbiome characteristics to test for evidence of a gut-brain axis. Our results from this model songbird species will build a foundation for future research, including understanding the microbiome during critical developmental stages (e.g., song learning) and in wild populations.

17-4 SMEDLEY, GD*; SERB, JM; Iowa State University; *gdsmedley13@gmail.com*

Molluscan Transcriptomes Suggest a More Complex Visual Cycle Homologous to Vertebrates

Photoreceptive organs have evolved as many as 65 times over the course of evolutionary history. Interestingly, nearly all light sensitive structures function via the same pathway of phototransduction. Phototransduction is a two step process which causes a conformational change of the photopigment upon light absorption and then requires resetting by reuptake or recycling of the bound retinal isomer. The latter half of the phototransductive pathway is known as the retinoid visual cycle. The molluscan visual cycle functions via retinochrome which photoisomerizes all-*trans* to 11-*cis* retinal by absorbing a photon and a shuttle protein transports the retinal isomers between the photoisomerase and the opsin. In vertebrates, retinal is recycled using shuttle proteins to transport the retinal between cell lines and through a well-characterized complex of enzymes for phototransduction or storage. Insects possess bistable opsins allowing retinal recycling within the opsin; however, recent studies have shown the enzymes of insects are homologous to those found in the vertebrate visual cycle. Changes in the understanding of the insect visual cycle and lack of a described non-light dependent molluscan visual cycle leads one to challenge the current simplicity of the molluscan visual cycle. To investigate this pathway in molluscs, published transcriptomes were searched for proteins involved in vertebrate or insect visual cycles. The results show the presence of RPE65, CRALBP, RDH5, and RDH12, in molluscan species, suggesting 1) molluscs possess a more complex visual cycle and 2) the origin of the retinoid visual cycle is before the protostome-deuterostome split.

122-3 SMITH, MG*; WESTGATE, AJ; KOOPMAN, HN; Harvard University, UNC Wilmington; *mollygablersmith@gmail.com*

Adipose tissue in diving animals: measuring the potential for gas exchange

Diving tetrapods are a biologically diverse group; however, they are all under similar constraints: oxygen limitation and increased hydrostatic pressure at depth. Adipose tissue is an interesting tissue to study, due to its physiologically important roles (e.g. metabolic energy storage, regulation of energy balance and thermoregulation) and because nitrogen (N_2) is 5 times more soluble in fat than in blood, creating a potential N_2 sink in animals consistently diving to depth. We examined the adipose tissue of diving tetrapods (3 species of seabirds, 3 sp. of sea turtles, 3 sp. of pinnipeds and 10 sp. of cetaceans), focusing on how adipose tissue structure allows these animals to cope with the physiological demands of diving. Adipose tissue microvessel density and diffusion distance were used to evaluate the comparative potential for aerobic activity (i.e. O_2 delivery). Long duration divers (i.e. beaked whales, > 120 min.) had relatively lower microvessel density (2.6 ± 0.5%) and greater diffusion distances (44.0 ± 13 μm), compared to short duration divers (e.g. eider ducks, < 2 min.; 4.4 ± 1.7% and 24.7 ± 9.9 μm). We hypothesize that beaked whale adipose tissue characteristics may function to minimize energetic costs during diving. Previous research indicates that lipid composition (lipid classes and short chained fatty acids [FA]) in some whales is an important factor determining N_2 solubility. However, there was no relationship between FA profile and N_2 solubility in the animals studied; species with similar FA profiles had different N_2 solubility values. The 3D structure of intact lipid molecules may elucidate the complex interactions between O_2, N_2 and lipid. Future studies should consider these interactions to better understand the physiological adaptations in diving animals.

84-4 SMITH, SM*; ANGIELCZYK, KD; KERBIS PETERHANS, JC; Field Museum of Natural History, Chicago, IL; *smsmith@fieldmuseum.org*

Vertebral number and spinal regionalization in large shrews (Soricidae)

In addition to having unique extra articulations on its vertebrae, the hero shrew (*Scutisorex*) is unusual in having almost twice as many lumbar vertebrae as other shrews of its size. Other than being noted in descriptive literature, this increase in vertebral number has received little attention; there has been no investigation of how it might reflect the elusive function of the highly modified *Scutisorex* spine. Comparisons of individual vertebrae and whole-column characteristics between *Scutisorex* and other large shrews are also lacking, despite the fact that such studies could give insight into i) function of particular vertebral regions in shrews with and without external vertebral modifications, and ii) developmental patterns driving regional proportions. We collected μCT scans and linear measurements of cervical, thoracic, and lumbar vertebrae in two species of *Scutisorex* and three other species of large shrews. We compared a variety of linear vertebra measurements, and trabecular bone characteristics of each centrum, across species. Further, using this combined suite of measurements, we executed principal coordinates analysis and segmented regression to detect unique vertebral regions in each taxon. Our results show that relative to other large shrews, *Scutisorex* has a shorter thoracic region and longer lumbar region, and, despite having more dorsal vertebrae than other species, does not have a proportionally longer body length. Regionalization signals vary within and across the five species, but generally suggest that functional regions may not correspond exactly with traditionally recognized anatomical regions of the column, and that the extended lumbar region in *Scutisorex* may afford it an additional functional region.

3-4 SMITH, NM*; DICKERSON, AK; University of Central Florida; *smithni@knights.ucf.edu*
Mosquitoes use multiple bounces to engage landing zones
In this experimental study we film the landings of *Aedes aegypti* mosquitoes to characterize landing strategies and kinetics, limitations, and the passive physiological mechanics they employ to engage a surface. A typical landing on a vertical surface involves 1-2 bounces before the mosquito firmly affixes to a surface, which act to reduce inbound momentum by more than half. Mosquitoes initially approach landing surfaces at 0.2 - 0.6 m/s, decelerating to zero velocity in approximately 3 ms at accelerations as high as 13 gravities. Impacts are damped by deforming forelimbs and buckling of the proboscis, which also serves to distribute the impact force, lessening the potential of detection by a mammalian host. The incoming threshold velocity which produces rebound too vigorous for tarsal attachment was observed to be approximately 1.35 mph, indicating host motion is an effective deterrent against mosquito bites.

125-3 SOLLA, AL*; O'ROURKE, C; ANDERSON, A; RENN, SCP; Reed College; *solla.auror@reed.edu*
Secret's in the Sauce: Hormones and Behavior in Julidochromis marlieri
Julidochromis marlieri, a socially plastic African cichlid, naturally establishes pair bonds between relatively larger and more aggressive dominant females and smaller subordinate males in both the wild and in the lab. However, these fish will also form pairs with a relatively larger male and a smaller female, and exhibit a reversal of their natural sex-biased behaviors. Here we investigate the hormonal profiles associated this plastic switch in social behavior. We collected gonadal hormones and behavioral measurements from male and female *J. marlieri* in both dominant and subordinate conditions over several weeks. Analysis of three sex hormones—17 -estradiol, testosterone, and 11-keto testosterone—showed that 11-keto testosterone concentration correlated positively with increased dominance and aggression in both males and females, with no significant correlation found between dominance and testosterone or 17 -estradiol in either sex. This further expands the importance of 11-keto testosterone in teleost social behavior, and illuminates the appropriate hormone for further manipulation and functional analysis in *J. marlieri*.

84-1 SOMBKE, A*; MUELLER, CHG; University of Vienna, Department of Integrative Zoology, University of Greifswald, Zoological Institute and Museum ; *andy.sombke@univie.ac.at*
Evolutionary transformations of centipede ultimate legs
In comparison to locomotory legs, the last pair of legs in Chilopoda – the ultimate legs – is particularly unique as no other legs in centipedes show a comparable functional, morphological, and behavioral diversity. These evolutionary transformed appendages are never or only rarely used for locomotion and can exhibit different morphologies associated with different functions. Sexual dimorphic characteristics suggest that ultimate legs play a pivotal role in intraspecific communication, mate finding and courtship behavior. Thus, centipede ultimate legs provide an excellent opportunity to explore diverse pathways of leg transformations. Ultimate legs in Scutigeromorpha (house centipedes) are extremely elongated and resemble antennae. The diversity, abundance and distribution of sensory structures, their association with elaborated primary processing centers in the nervous system, as well as electrophysiological experiments strongly suggest that these multi-annulated legs function as sensory appendages at the posterior end of the body. In Geophilomorpha (soil centipedes), ultimate legs may be sexually dimorphic and frequently covered with thousands of cuticular structures. However, these hairs do not resemble sensilla, but shafts of glandular structures. Thus, geophilomorph ultimate legs evolved a secretory function of yet unknown relevance. We show that centipede ultimate leg transformations are by no means restricted to external morphology, but that this particular centipede character was subjected to a cascade of adaptations.

13-1 SOMJEE, U*; ANZALDO, S; MARTING, PM; PAINTING, CJ; POWELL, E; HICKEY, T; Smithsonian Tropical Research Institute, Panama, Arizona State University, USA, University of Auckland, New Zealand, University of Waikato, New Zealand; *ummat.s@gmail.com*
Extreme size variation in an armed weevil sheds light on the relationship between body mass and metabolic rate
The relatively low metabolic rates of larger organisms compared to small organisms is among the most pervasive trends in biology. Yet, most studies that examine the relationship between body mass and metabolic rate are conducted across species. Here we examine resting and recovery metabolic rates in a species of brentine weevil that vary more than an order of magnitude in size among adults. These weevils also exhibit extreme positive allometry of their sexually selected rostra, used as weapons during male-male contests; larger male carry proportionally larger weapons for their body size. We find resting metabolic rates scales with a similar slope as those found across species, consistent with low metabolic scaling. Metabolic rates after sustained activity were higher in all individuals yet scaled with the same hypo-allometric relationship with body size as during rest. Further, cuticle tissue of the weapon scales in direct proportion to mass of the weapon, while soft tissue within the weapon scales with low allometry. These results suggest that as these weapons get larger in size they are comprised of a proportionally higher mass of metabolically inactive structural tissue and proportionally less active metabolic tissue. Our findings reveal the low scaling of metabolic rate in a single species is consistent with across species trends, and that larger individuals carry disproportionally larger weapons but likely at a reduced metabolic cost per gram of tissue.

13-3 SORLIN , MV*; MARKS, JR; JOHNSON, MA; HUSAK, JF; LAILVAUX, SP; University of New Orleans, LA, Trinity University, San Antonio, TX, University of Saint Thomas, Saint Paul, MN ; *mvsorlin@uno.edu*

Effect of Exercise Training on Brain Allometry and Cognitive Abilities in Anolis carolinensis

Brain size is highly variable across the animal kingdom. Multiple studies investigating this variation point at a correlation between cognitive abilities, brain mass and performance enhancement. For instance, performance enhancement lead to the general increase in brain volume in humans and hippocampal neurogenesis in mice. However, vertebrates outside of the mammalian clade have received very little attention, making it difficult to distinguish general evolutionary patterns across taxa. In order to address this gap, we investigated the effect of training exercise on cognitive abilities and brain allometry in a species of lizard (*Anolis carolinensis*). Individuals were trained for both endurance and sprint for an extended period of time. Following this treatment, they were subjected to a cognitive test using spatial recognition. We hypothesize that trained individuals will demonstrate higher navigational skills than untrained lizards as well as potentially exhibit an increase in brain size compare to individuals from the control group.

139-2 SOTO, D*; GOLDMAN, DI; Georgia Institute of Technology; *dsoto7@gatech.edu*

Improving performance of a legged robot on bumpy ground via gentle tail taps

Robot locomotion on uneven terrain is typically assumed to require complex sensing, control and planning. However, discoveries of the role of mechanics and nonlinear dynamics in running animals and legged robots indicate that stabilization and performance increases can be facilitated via leveraging of non-locomotor structures. Here we examine how an open-loop controlled tail affects performance of a legged robot on uneven terrain. We constructed a RHex-type quadruped robot (L=27cm, m=2.8kg) with compliant C-legs (d=8cm) and a tail (L=20cm, m=0.4kg). Each leg was controlled via a cascaded PID position-velocity control system, with setpoints determined by the duty factor and phase lag of a chosen gait. A landscape consisting of a Gaussian height distribution of 128 blocks (h=0-10cm, w=5cm) generated failures in no-tail robot by either catching a leg or trapping the robot on its belly. We first tested two tail behaviors which we hypothesized would improve performance. The first maintained a constant angle with the body, essentially adding a fifth point of support, and the second oscillated the tail periodically, resulting in intermittent ground contact. In all tests, stability (the average summed roll and pitch of the robot), energy cost (average current draw), and success probability (full transit across the testbed) were measured. In 106 total trials, both tail strategies improved the success probability from 60% (no tail) to 90-100%. Constant angle led to stable locomotion (average of 5.5°) but with high energy cost (0.7A), whereas tapping displayed higher instability (9°) but lower energy costs (0.5A). A "gentle tap" strategy which combined both behaviors demonstrated high success probability (100%), good stability (5.7°), and low energy cost (0.35A), thereby improving locomotor performance with minimal control additions.

34-1 SPAGNA, JC*; ESPINOSA, AJ; CREWS, SC; William Paterson University, California Academy of Sciences; *spagnaj@wpunj.edu*

Grass Spiders of North America and Europe: A Long-Distance Relationship Lasting 50 Million Years

The grass spider subfamily Ageleninae (Araneae: Agelenidae) is distributed throughout North America. However, in the western part of the distribution, they are incredibly species rich with 129 species in 10 genera endemic to the region. However, other North American agelenine taxa with widespread and Gulf/Caribbean distributions (3 genera, 28 species) are clearly diverged morphologically from the Western taxa, based on spinneret shape and male genitalia. The affinities of the North American taxa with worldwide Agelenidae, particularly the Eurasian taxa, have been difficult to decipher. Here we attempt to test both the monophyly of the North American taxa and their relationships to worldwide taxa. To answer these two questions we analyzed genetic data from targeted genes using Bayesian likelihood to construct a phylogenetic hypothesis. A monophyletic relationship between the western and eastern North American groups was not recovered, and the eastern North American group is more closely related to the Eurasian taxa. Additional analyses using molecular clock estimates for the age of the subfamily (~50 MY) disallow an obvious vicariant event induced from the opening of the Atlantic at 66 MYA, leaving trans-oceanic dispersal as a potential cause for the surprising sister relationship.

115-3 SPIERER, AN*; MOSSMAN, JA; RAND, DM; Brown University, Providence, RI; *adam_spierer@brown.edu*

Dissecting the genetic modifiers of flight performance using the Drosophila Genetic Reference Panel

Insect flight is a complex and polygenic trait requiring the coordination of many genes across disparate systems throughout ontogeny. Identifying loci that contribute to complex traits is exceptionally challenging because traditional Genome Wide Association Study (GWAS) methods are best for identifying fewer loci with larger effect sizes. However, most complex traits and behaviors are comprised of many loci with small effect sizes. Recently developed tools for GWAS analysis are revolutionizing the field of quantitative genetics, better enabling us to map more subtle genetic underpinnings of complex traits. Accordingly, our study aimed to leverage these newer methodologies in a powerful Drosophila genetic model to identify genetic modifiers of flight performance. Using the Drosophila Genetic Reference Panel, a set of nearly 200 isogenic *Drosophila melanogaster* lines representing a snapshot of natural variation, we were able to begin mapping genotype to phenotype. Using a combination of traditional methods and methods recently developed for human GWAS--never before applied to a Drosophila model--we were able to identify a number of significant SNPs (individual and epistatic), genes, and pathways that broadly mapped to neuron and muscle function and development, regulators of gene expression, and previously undescribed functions. These results aim to expand our understanding of the genetic basis of aerial locomotor performance, unravel patterns of complexity underlying polygenic phenotypes, and facilitate research in other model organisms surrounding the genetics of insect flight. Future directions are underway to investigate the genetic modifiers for robustness of the flight performance phenotype, which preliminary evidence suggests is strongly tied to loci modifying gene expression.

103-2 SPRAYBERRY, JDH; Muhlenberg College; *jordannasprayberry@muhlenberg.edu*

Compounds without borders: a novel paradigm for quantifying complex odors and responses to scent-pollution in bumblebees

Bumblebees are critical pollinators whose populations have been declining over the past several decades. Successful foraging improves colony fitness, thus understanding how anthropogenic influences modulate foraging behavior may aid conservation efforts. Odor pollution can have negative impacts on bumble- and honey-bees foraging behavior. However, given the vast array of potential scent contaminants, individually testing pollutants is an ineffective approach. The ability to quantitatively measure how much scent-pollution of a floral-odor bumblebees can tolerate would represent a paradigm shift in odor-pollution studies. Current statistical methods derive the dimensions of an 'odor-space' from the odorants within a dataset; therefore, when the dataset is modified the odor-space itself is reconstructed. In this way statistical methods such as principle components analysis (PCA) or non-metric multidimensional scaling (NMDS) have excellent descriptive power, but are less effective at prediction This study presents an alternative method of analyzing complex odor blends based on the encoding properties of insect olfactory systems. This "Compounds Without Borders" (CWB) method represents odors as a vector in a multidimensional space representing the functional group and carbon characteristics of their component odorants. The dimensions of this space are independent of the data described within it. These vectors allow the angular distance between any two odors to be calculated – including a learned odor and its polluted counterpart. Data presented here indicate that CWB-angles are capable of both describing and predicting bumblebee odor-discrimination behavior: odor pairs with angular distances in the 20-29° range are generalized, while odor pairs over 30 degrees are differentiated.

35-8 SQUARE, TA; University of California, Berkeley; *square@colorado.edu*

Stem Cell Markers Reveal Conservation of Tooth and Hair Regeneration

Vertebrates interact directly with their environment largely through their epithelia. To enhance these interactions, most vertebrates deploy various accessory structures in these high-contact regions of their bodies, called epithelial appendages. These include scales, hair, feathers, teeth, and many other organs. Despite their vastly different shapes and compositions as mature organs and structures, epithelial appendages begin development by relying on a surprisingly conserved set of signals and cell-cell interactions, and exhibit curiously similar histogeneses. Another character shared by most epithelial appendages is their capacity to regenerate. In most cases, this process is undergone constantly throughout the life of an organism, either in a facultative or obligate manner (i.e. prompted by damage or constant renewal). Given the recently published evidence for the conservation, and perhaps homology, of epithelial appendage development, we hypothesized that the regenerative process would also be conserved between disparate organs such as teeth and hair, namely that the stem cells contributing to this process would be marked by similar sets of gene expression. Using previously published information on gene expression during mammalian hair regeneration, we assayed the expression of stem cell markers during tooth replacement in two fish species: zebrafish (*Danio rerio*) and the threespine stickleback (*Gasterosteus aculeatus*). We find expression overlap consistent with a conserved regeneration process in these distantly-related epithelial appendages.

74-3 SRYGLEY, RB; USDA-Agricultural Research Service; *robert.srygley@ars.usda.gov*

Diapause plasticity allows insects to cope with drought at high and low elevations

Semi-arid rangelands of the western US are sensitive to climate change, with droughts projected to increase in frequency and duration in the latter half of the 21st century. These extreme events also impact many insect populations. We hypothesized that if drought could prolong diapause of Mormon cricket eggs, it might synchronize embryonic development and hatching after moisture is restored. We compared a high elevation WY population with two (OR and ID) at lower, drier elevations where we predicted the eggs would be more tolerant of desiccation. We predict that eggs will show the least development in drought during the first growing season, but the undeveloped eggs in the driest treatments will show the greatest development following restoration of moisture and a second growing season. For WY, the two drier treatments had significantly more eggs prolonging development until after the first warm period than the two wetter treatments. Whether those eggs in prolonged diapause developed in the second or subsequent warm periods did not differ among moisture treatments. Significantly fewer OR embryos developed at the driest treatment compared to the others, and almost all of the ID eggs developed irrespective of the moisture treatment. In conclusion, Mormon crickets can delay embryonic development to avoid drought until favorable conditions for growth and hatching are restored. Because undeveloped eggs lose less water than developed embryos, plasticity of WY mitigates the drought effect on egg viability. Eggs from high elevation were the most tolerant due to their capacity to postpone development to any one of several more favorable growing seasons. OR also reduced egg loss by prolonging diapause relative to ID that developed in even the driest condition. Although drought did not result in a concentration of development, diapause plasticity allowed the katydids to await more favorable conditions.

129-2 ST. JOHN, ME*; MARTIN, CH; University of California - Berkeley; *stjohn3@berkeley.edu*

A tale of scales and snails: behaviorally mediated traits drive the evolution of novelty in a radiation of Cyprinodon pupfishes

Understanding how organisms adapt to novel ecological niches is an outstanding question in evolutionary biology. Adaptation often includes shifts in foraging preferences, kinematics, and trophic morphology. Here we investigated behavioral, kinematic, and morphological adaptations to the novel ecological niches of of scale- and snail-eating in a recent radiation of *Cyprinodon* pupfishes endemic to San Salvador Island, Bahamas. Scale-eating and snail-eating pupfish both arose from an algae eating ancestor 10 kya, but display unique adaptations which allow them to occupy novel niches. First, we compared the feeding kinematics across pupfish species and their F1 hybrids during scale-biting and suction-feeding in the lab. We found that scale-eaters had peak gapes that were twice as large as other groups, but simultaneously had gape angles that were 32% smaller—which appears to be behaviorally mediated. We also found that the scale-eater's unique kinematic profile resides on a performance peak. Second, we investigated whether the novel nasal protrusion of the snail-eating pupfish is adapted for the novel behavior of 'shelling' (i.e. removing snails from their shells). We measured snail-shelling preferences across pupfish species and F1 and F2 hybrids using behavioral assays and their nasal protrusion distance. We found that snail-eaters and snail-eating hybrids consumed more snails than other groups, but that nasal protrusion distance did not affect an individual's ability to consume more or larger snails in the F2 hybrids. Similar to scale-eating, this suggests that a shift in feeding behavior, such as foraging preference, is driving the evolution of the snail-eating specialist. Ultimately, we found evidence for the importance of behaviorally-mediated traits during adaptation to novel trophic niches.

83-3 STADTMAUER, DJ*; CHAVAN, AR; WAGNER, GP; Yale University; *daniel.stadtmauer@yale.edu*
Baby Light My Fire: "Cooperative Inflammation" in Marsupial Pregnancy
Marsupials and placental mammals have diverged substantially in life history: marsupials produce highly altricial young which complete development attached to the mother's nipple, whereas placental mammals have evolved the potential for extended pregnancy. The traditional explanation for this pattern is that marsupials are constrained by a rejection-like immune response upon contact of fetal and maternal tissues that is incompatible with prolonged gestation. Indeed, transcriptomic and histological studies of the opossum *Monodelphis domestica* have shown that an inflammatory phase of pregnancy begins after intrauterine hatching from the shell coat and progresses until birth. However, it has remained unclear whether this phenomenon is defensive inflammation, a tissue damage response, or a modified pregnancy-specific derivative of inflammation. If the constraint model for marsupial pregnancy is accurate, we would expect that inflammation proceeds as in a normal defensive immune response of host to pathogen, and that the fetus is expelled because it is not masked from the maternal immune system. Predictions of this model were tested by identifying the cellular origin of inflammatory signals in opossum pregnancy using immunohistochemistry and *in situ* hybridization. In at least two key pathways, prostaglandin synthesis and the cytokine interleukin-17, pro-inflammatory signals were found to originate from both the fetus and the mother, rather than the mother alone. We therefore reject that opossum parturition is a maternal attack upon the fetus, and instead propose that inflammation has been evolutionarily stabilized in this marsupial, potentially as a way for the fetus to effect its own birth. We name this new model *cooperative inflammation* and shall discuss its implications for the evolutionary narrative of mammalian viviparity.

100-5 STAGER, M*; SENNER, NR; TOBALSKE, BW; CHEVIRON, ZA; University of Montana, University of South Carolina; *maria.stager@umontana.edu*
What makes the Snow Bird fit for winter? The mechanisms underlying seasonal physiological flexibility
Organisms maintain dynamic regulatory systems that can confer the flexibility to reversibly match their phenotype(s) to fluctuating environmental conditions. This process often involves the dramatic modification of multiple subordinate traits. However, the relative influence of these component traits on whole-organism performance is poorly understood in natural systems. As a case study, we explore the contribution of subordinate phenotypes to avian body temperature regulation in the cold by combining assays of gene expression, tissue-level- and whole-animal physiology of Dark-eyed Juncos (*Junco hyemalis*) exposed to controlled temperatures. This work indicates that organismal performance is disproportionally influenced by a few subordinate traits and reveals an undocumented mechanism of avian thermoregulation. We then ask—Do populations within this geographically widespread species vary in their degree of flexibility? To address this, we replicated this approach across five additional *Junco* populations that vary in the natural thermal regimes they experience and interpret these patterns in light of historical demographic processes. Our results shed light on the mechanisms underlying avian body temperature regulation and the ability of natural populations to respond to seasonal environmental fluctuations.

14-7 STARK, AY; Villanova University; *alyssa.stark@villanova.edu*
Tenacious Toes and Fastening Feet: Biological Adhesive Systems in Complex Environments
Organisms that temporarily attach in order to move within their environment face potential failure with every step and release cycle. This potential for failure prompts unique morphological, biomechanical, and behavioral attachment structures and strategies that are likely tuned to current spatial and temporal conditions. Rather than studying the success of these systems in pristine laboratory conditions, I study failure in natural and semi-natural conditions to better understand the functional morphology of temporary adhesion. My observational and experimental work shows that biological attachment systems fail, sometimes spectacularly, but often remain successful in the conditions that matter. The focus of my research program is to understand the conditions that matter and how biological adhesive systems maintain high performance and versatility when it counts. Currently I use three biological adhesive systems to explore adhesive performance in challenging conditions: geckos, ants, and sea urchins. Each system offers a unique mechanism and set of challenges that must be overcome. For instance, geckos from the tropics must adhere in hot, humid, and wet conditions, tropical arboreal ants must adhere to superheated substrates, and sea urchins in the intertidal must adhere to rocky substrates while resisting intense wave forces. In all instances, failure is rare when the adhesive system is matched with common environmental conditions. When the biological adhesive system is not matched with common environmental conditions adhesive performance may be too low or too high to be biologically functional. By exploring the successes and failures of biological adhesive systems in complex environments, we improve our understanding of the functional morphology of these systems, providing valuable insight into the ecology and evolutionary development of adhesion and potential for bio-inspired synthetic design.

S5-3 STARK, A Y*; YANOVIAK, S P; Villanova University, University of Louisville and Smithsonian Tropical Research Institute ; *alyssa.stark@villanova.edu*
Adhesive Performance of Tropical Arboreal Ants on Canopy Substrates
The surface characteristics of forest canopy substrates are highly variable over relatively small temporal and spatial scales. Substrates often differ in roughness, surface wettability, temperature, moisture level, and inclination over minutes and millimeters. This extreme variation favors the evolution of adhesive and attachment mechanisms in ants and other cursorial, arboreal organisms. Ants use soft pads coated with an adhesion-mediating fluid and claws to prevent falling. Our observational and experimental work suggests three patterns. First, ant adhesive performance and running speed varies as a function of substrate type and condition. Second, ant adhesive performance and running speed are not consistently correlated across a range of substrate conditions. Third, adhesive performance and morphology vary with body size and phylogeny. Understanding the functional morphology of ant adhesion is fundamental to understanding ecological relationships in the highly competitive and dynamic canopy environment.

121-3 STARLING, JA*; GUATAM, S; HOWARD, LJ; MADSEN, SS; TIPSMARK, CK; UNIVERSITY OF ARKANSAS, FAYETTEVILLE, AR, UNIVERSITY OF SOUTHERN DENMARK, ODENSE, DENMARK; *jastanle@uark.edu*

Salinity effects on water and salt transport components in the intestine of Atlantic killifish (Fundulus heteroclitus)

Atlantic killifish is a hardy euryhaline teleost that thrives in both fresh water (FW) and seawater (SW). Compensatory salt transport in teleost fish is mainly branchial while volume regulation is renal in FW and intestinal in SW. Intestinal handling of imbibed SW must involve aquaporins, ion transporters and claudins. In this study of killifish, we analyzed salinity effects on the transcriptional, protein and morphological level to better identify the role of the intestine during the rapid salinity fluctuations experienced by an estuarine species. An organ distribution experiment was performed to analyze mRNA expression of known membrane proteins involved in water and ion transport. Aquaporin paralogs (aqp1, aqp8, aqp10a), two ion transporters (nka1a, nkcc2) and three claudin paralogs (cldn15a, cldn15b, cldn15like) were all expressed in both anterior and posterior intestine of all salinities but with segmental differences. Some genes showed elevated expression in SW compared to FW acclimated killifish (nkcc2, aqp1, aqp2), suggesting increased capacity for transcellular ion and water transport. Remarkably, cldn15b had 100-fold higher expression in posterior intestine only in FW acclimated fish. The minor or absent salinity regulation of many ion and water transport genes suggests partial maintenance of intestinal water handling capacity. However, some adjustment occurs and the dramatic elevated expression of cldn15b suggests a specific role of this paralog in the posterior intestinal segment but only in FW. Confocal microscopy revealed brush border localization of Aqp1 and significant morphological differences between anterior and posterior intestine supporting functional specialization.

37-7 STAYTON, CT*; PRICE, SA; WAINWRIGHT, PC; FRIEDMAN, ST; Bucknell University, Clemson University, UC Davis, UC Davis; *tstayton@bucknell.edu*

What does it take to make an eel? Convergence and adaptation in the evolution of an eel-like body plan

True eels (Anguilliformes) are characterized by a distinctive elongate morphology. Ichthyologists have informally, by utilizing the term "eel" in common names, identified a number of additional lineages with this morphology (e.g., "electric eels", "swamp eel"). The apparent ubiquity of the "eel morphotype" has led researchers to search for common selective pressures towards elongation. However, a quantitative study of the degree to which this frequency requires adaptive explanations has never been conducted. Here we use a multi-dimensional database of body shape in teleost fishes to address the following questions: besides elongation, are there other distinctive morphological characteristics of true eels? Do other "eel-like" fishes occupy the same region of shape space as true eels? How many times have lineages invaded this region of shape space, and is this greater than expected without adaptive evolution? Besides being relatively long, true eels are also characterized by flat heads, narrow mouths, and tall caudal peduncles (relative to the rest of the fish). Few "eel-like" lineages occur within the region of shape space defined by true eels, but many are close to this region. Overall, 23 lineages have invaded the "true eel region" of shape space; this is not significantly greater than the number expected under a non-adaptive BM model. Thus the eel body plan, while distinctive, appears fairly easy to access. Although the various lineages which have adopted this form have probably done so for adaptive reasons, our results provide no evidence that a single explanation (e.g., evolution towards a single adaptive peak) is necessary to account for the diversity of "eel-like" teleosts.

112-6 STEELE, AN*; MOORE, PA; Bowling Green St Univ, Univ of Michigan Biological Station; *ansteel@bgsu.edu*

Behavioral consequences of per- and poly-fluorinated alkyl substances (PFAS) exposure on Northern Michigan crayfish species

The need for bioindicator species to aid the assessment of anthropogenic impacts on aquatic ecosystems is currently rising due to the continued degradation of environments. Several characteristics of crayfish make them suitable candidates as bioindicators: global distribution, high population densities, low migratory rate, sensitive physiology and behaviors. The demonstrated sensitivity of crayfish as an established bioindicator for an array of anthropogenic toxicants raises interest in the sensitivity of crayfish to emerging contaminants. The emergent contaminant family, per- and poly-fluorinated alky substances (PFAS) has gained research attention due their widespread detection and stability within the environment. Previous research has demonstrated PFAS causes negative effects on the reproductive, endocrine, immune and nervous systems of experimental organisms, however, behavioral effects have not been well documented. The aim of this study was to investigate the behavioral consequences of PFAS exposure on crayfish species and the utility of these organisms as a bioindicator model for PFAS contamination. Differences in the foraging and antipredator response of crayfish were compared between animals collected from various polluted locations in Northern Michigan. Water chemistry sampling provided verification of PFAS concentrations at crayfish sampling sites and was used to determine the relationship between behavioral deficits and PFAS exposure. Analysis resulted in differences in two ecologically relevant bioassays. Due to the prevalence and uptake of PFAS compounds by aquatic organisms, a suitable bioindicator species and further study on fitness related behaviors that may be affected by PFAS are critical.

71-5 STEELE, TJ*; BARKAN, CL; BAAS-THOMAS, N; ZORNIK, E; Reed College; *thesteel@reed.edu*

Investigating the neuronal basis of sex-specific vocal behavior

Sexually dimorphic behaviors are useful systems in which to study the role of hormones in generating behavioral diversity within a species. The mating calls of *Xenopus laevis* are sexually distinct; female calls are slow and monophasic, while male calls are faster and biphasic. The circuit that produces these vocalizations is a central pattern generator consisting of androgen sensitive premotor and motor nuclei. The production of male song requires circulating androgens; gonadectomized male song degrades, while androgen-treated females (T-females) develop the ability to produce male-like calls. We used whole-cell electrophysiology to investigate the vocal circuit changes underlying the masculinization of T-female vocal behavior. We identified premotor neurons in T-females with vocal activity during song resembling that of male premotor vocal cells. These cells increased in size over the course of testosterone treatment, reaching male-like values after 8 weeks of androgen exposure; they also possessed the hyperpolarization activated cation current, I_H, and displayed NMDA receptor-dependent oscillations, both of which are characteristic of male premotor cells. In males, vocal cells in the premotor nucleus can be categorized into two groups based on differences in activity during song. T-female vocal neurons also separated into these two groups when compared with male cells. Both cell types were found throughout the course of androgen treatment. Our findings suggest that the masculinization of vocal behavior involves changes to cell morphology and intrinsic currents in the premotor nucleus, and involves both premotor cell types.

82-2 STEELE CABRERA, S*; HUNT, TS; HADDAD, NM; LUCKY, A; DANIELS, JC; University of Florida, Gainesville, FL, Michigan State University, East Lansing, MI; *ssteelecabrera@flmnh.ufl.edu*

Measuring the Outcome of Reintroduction Efforts for an Endangered Butterfly

Reintroduction of imperiled species has become a popular conservation strategy; rigorous monitoring of reintroduced organism is vital to assessing the outcomes of these efforts. The Miami blue butterfly (*Cyclargus thomasi bethunebakeri*), a federally endangered Lycaenid endemic to Florida, is the focus of an ongoing captive breeding and reintroduction project. Captively reared pupae and adult butterflies were released into large in-situ enclosures at two sites in the Florida Keys. Released individuals were monitored in order to estimate pupal survival, adult butterfly longevity, fecundity, and egg survival. In addition, a variety of environmental factors were measured at each site, including precipitation and vegetative characteristics. Successful establishment of reintroduced butterflies occurred quickly at one site, where individuals went through multiple generations without further intervention by researchers, while establishment did not occur at the second reintroduction site. Release of adult butterflies was associated with greater fecundity than for pupal reintroductions, likely due to mortality of pupae in the field. Adult butterfly longevity as well as fecundity were higher in field enclosures with greater cover of one larval host plant but not a second larval host plant, as well as higher overall plant cover. These results indicate that Miami blue butterfly may experience higher survivorship on one larval host plant versus the other, though a lab experiment indicated that larval survival was not significantly different between the two host plants. These results indicate that conservation efforts should include habitat restoration with larval host plants.

53-5 STEFFENSON, M*; GARCIA, M; VALENTINI, A; VARGAS, R; St. Edward's University; *msteffen@stedwards.edu*

The Effect of Elevated Temperature on Basal Immunological Activity in The Wolf Spider Tigrosa helluo

Climate changes models predict that Earth will continue to see increasing temperatures over the coming decades. However, the effect that such elevated temperatures will have on organisms is in many cases hypothetical. The impact of increased temperatures on ectotherms is even more critical to understand as they cannot regulate their own body temperatures. Because of these reasons, understanding how future climate change affects the ability of organisms to alter their energy budgets is critically important. This study aims to determine the effect of elevated temperatures on the basal immunological activity of the wolf spider, *Tigrosa helluo*. Female spiders with all eight legs intact were collected at night from the St. Edward's University campus. Specimens were massed and stored overnight in plastic crispers at room temperature. The following morning, spiders were transferred to environmental chambers that were either at ambient temperature (36 degrees Celsius) or an elevated temperature (42 degrees Celsius). Spiders were offered one cricket on day three in the incubators and had water provided ad libitum. After five days in the appropriate incubator, spiders were massed again and had their hemolymph extracted for immunological assessment. Preliminary data indicates that spiders in the elevated temperature gained weight from consuming prey, as did the ambient temperature spiders, but elevated temperature specimens then lost weight by the end of the experiment. Anecdotally protein concentration appears to be lower in spiders held at an elevated temperature. Data collection is ongoing and future assays will include prophenoloxidase activity (a protein commonly associated with immune activity among invertebrates) and peroxidase activity (an antioxidant).

128-3 STEIN, LR*; HOKE, KL; University of Oklahoma, Colorado State University; *laura.stein@ou.edu*

Parental and personal experience with predation risk interact in shaping phenotypes in a sex-specific manner

Evolutionary history, parental experience, and personal experience provide distinct avenues by which organisms adjust phenotypes based on environment, yet the mechanisms mediating phenotypic variation on these time scales may interact. Here we examine how population history, parental environment and juvenile experience interact to modify offspring phenotypes in the Trinidadian guppy (*Poecilia reticulata*). Parents from across four populations (two high-predation and two low-predation) were raised in the lab either with or without predator cues, and offspring were split and raised either with or without predator cues. We found that parental effects impacted both offspring size and multiple behaviors. For most phenotypes, male and female offspring differed in consequences of parental and personal experience. Indeed, sex was a stronger predictor of the interaction between parental and personal experience than population history. Altogether, our results suggest that parental effects and offspring experience are weighted differently in males and females, and highlight the complex interactions between transgenerational and developmental plasticity during development.

S1-5 STEINBERG, DK*; CONROY, JA; THIBODEAU, PS; Virginia Institute of Marine Science, College of William & Mary; *debbies@vims.edu*

New Insights Into Patterns of Zooplankton Abundance Along the Rapidly Changing Western Antarctic Peninsula

During the last two decades the rapid regional warming and sea ice decline in the western Antarctic Peninsula (WAP) region observed since the mid-twentieth century has plateaued. While the long-term trend in warming and sea ice loss is still significant, there has been a notable increase in sea ice extent and duration, and its interannual variability, since the late 2000s in the coastal WAP. The Palmer, Antarctica Long-Term Ecological Research (PAL LTER) program is investigating marine ecosystem response to both long-term regional warming and shorter-term reversals along the peninsula's marine continental shelf. Changes in the distribution and relative abundance of Antarctic krill (*Euphausia superba*) and other zooplankton that play a central role in the food web in many cases can be tied to warming and sea ice trends, and to the atmospheric circulation patterns that underlie these trends. For example, episodic recruitment sustains the Antarctic krill population along the WAP, and strong recruitment since 2011 is coincident with enhanced phytoplankton productivity and recent sea ice increases. A long-term increase in another krill species in the southern part of the study region is also attributed to increased phytoplankton production or more favorable timing of ice-retreat leading to subsequent blooms. Abundance of gelatinous salps and pteropods (pelagic snails) were significantly affected by sub-decadal climate oscillations (e.g., El Niño Southern Oscillation). We discuss the importance, and challenges, of understanding the effects of this environmental variability on the WAP food web, and some potential effects on regional carbon cycling.

27-4 STEINWORTH, BM*; MARTINDALE, MQ; RYAN, JF; University of Florida Whitney Laboratory; *bsteinworth@ufl.edu*
The evolution of cnidarian and bilaterian Hox genes
Hox genes control patterning of body regions along the bilaterian anterior-posterior axis and are found in cnidarians, making them good targets for better understanding evolution of axial patterning in animals. The relationships between cnidarian and bilaterian Hox genes remain unclear, possibly because previous research has focused on limited cnidarian taxa Here, we present a phylogeny of Hox and related homeobox genes using the broadest cnidarian sampling to date, including representatives from Octocorallia and Hexacorallia as well as all four medusozoan groups, Hydrozoa, Scyphozoa, Staurozoa, and Cubozoa. One notable result is the phylogenetic placement of genes known in the anthozoan Nematostella vectensis to be involved in specifying the directive axis, a secondary body axis perpendicular to the primary cnidarian oral-aboral axis. Phylogenetic placement suggests the directive axis genes were lost in medusozoans, potentially as an adaptation to pelagic open-ocean life. Overall, our results are consistent with a scenario of significant Hox gene loss in both cnidarians and bilaterians.

11-2 STEVENS II, DR*; GRAHAM, MA; BADJIS, CB; MASON, JN; BAKER, JA; FOSTER, SA; Clark University; *dalstevens@clarku.edu*
Differences in behavioral plasticity among populations of threespine stickleback experiencing a novel predation threat.
Rapid, novel changes to an organism's environment due to invasive species are a global threat to biodiversity. Behavioral shifts are often the first phenotypic response to such changes, particularly when the invasive species poses a predatory threat. The high level of plasticity inherent to most behavior may potentially permit population survival until adaptive changes can occur, and the initial behavioral plasticity itself may even facilitate adaptation. Thus, in order to fully understand how behavioral responses are shaped by novel environments created by invasive predators, it is important to consider both the behavioral responses and the degree of plasticity of that behavior. Northern pike, Esox lucius, is an invasive species in Southcentral Alaska, where it constitutes a novel, intense predatory threat to threespine stickleback, Gasterosteus aculeatus. In this experiment, we asked how antipredator behavior differs among stickleback from pike-invaded and pike-free populations. We quantified stickleback behavior after a simulated attack when placed in one of four chemical cue conditions, thus creating environments differing in the degree of threat (e.g. control vs alarm/predator cues) and specificity of threat (general conspecific alarm cue vs specific predator cue). Populations differed in whether they had experienced the cues associated with the invasive predator within their recent evolutionary history. We show population differences in general antipredator behavior to a simulated attack (differences among individuals in the control condition), as well as population differences in behavioral plasticity, with population-specific responses to chemical cue treatments. We discuss these results here in a broader evolutionary context.

47-3 STEVENSON, TJ; University of Glasgow; *tyler.stevenson@glasgow.ac.uk*
Rhythmic Epigenetics and the Neuroendocrine Regulation of Reproduction in a Seasonal Rodent.
The daily and yearly rotations of the Earth have provided a constantly changing environment that has driven the evolution of biological rhythms. The ability to adapt to future predictable climatic conditions is an ancient adaptation; therefore, it should not be surprising to observe biological rhythms at genomic, physiological, and behavioral levels across taxa. In this presentation, the conjecture that DNA methylation is an evolutionary ancient and essential component for the genomic regulation of biological rhythms will be outlined. The studies used male or female Siberian hamsters (*Phodopus sungorus*) to investigate the role of photoperiod, oestrous and hormonal regulation of DNA methylation and *de novo* DNA methyltransferase (*Dnmt3a/b*) expression in the hypothalamus and peripheral reproductive tissues (i.e. testis, uterus). Hypothalamic DNA methylation and *Dnmt3a/b* are elevated in long day (LD) summer-like breeding conditions. Short days (SD) and melatonin were sufficient to reduce hypothalamic DNA methylation and *Dnmt3a/b* expression. In females, hypothalamic *Dnmt3a* expression increased during the transition from proestrous to oestrous states. A single bolus injection of diethylstilbestrol (DES) and progesterone (E2P4) was sufficient to increase *Dnmt3a* cell numbers and *Dnmt3b* immunoreactive intensity in the suprachiasmatic nucleus (SCN). Upregulating DNA methylation *in vitro* reduced expression of vasoactive intestinal polypeptide, Vip, and the circadian clock gene, Bmal1. Conversely, SD increased global DNA methylation and *dnmt3a* expression in the testes and uterine tissue. Ovariectomy increased *Dnmt3a/b* uterine expression that was rapidly reduced after a single injection of E2P4. Altogether, the data reveal a dynamic and oscillatory role of DNA methylation for timing biological rhythms in reproduction.

87-8 STEVENSON, JPJ*; CHENEY, JA; DURSTON, NE; USHERWOOD, JR; WINDSOR, SP; BOMPHREY, RJ; University of Bristol, UK, Royal Veterinary College, Hatfield, UK; *jonathan.stevenson@bristol.ac.uk*
Avian wing suspension for gust rejection
Amid the gusty conditions of the low atmosphere, birds routinely fly where air vehicles of the same scale would struggle severely or even fail. Crucially important to birds' control abilities are their compliant, articulated flight surfaces, which offer aerodynamic load alleviation to help stabilize the torso and head. To gain understanding on these control mechanisms, we flew a barn owl (*Tyto alba*) through variable upward gusts and derived its wing and tail kinematics from synchronized multi-angle high-speed video. In all flights, the wings rotate upwards about the shoulder, yet the torso remains exquisitely stable; under the same conditions, a simulated owl with rigid wings is driven vertically off course. We conclude that the basic requirement for the observed stabilization is a shoulder hinge, which acts as suspension to modulate the transmission of initial aerodynamic load to the torso. That the torso stays consistently still in all flights suggests that wing inertia is particularly well tuned – hinge forces (hence motion) are all but eliminated as the gust is encountered, in the same way that jarring at the hand is cancelled out when a ball is struck with the sweet spot of a bat. The mechanism is fast and should reduce the active burden on the flight control system. Once wing elevation saturates and the suspension effect subsides, the wings pitch down, dumping yet more aerodynamic load to provide sustained rejection of the gust.

37-3 STEWART, TA*; LEMBERG, JB; SHUBIN, NH; The University of Chicago; *tomstewart@uchicago.edu*

The evolution of dermal rays in tetrapodomorph paired fins

Paleontological studies of the fin-to-limb transition have focused almost exclusively on endoskeletal evolution. However, comparative analyses of dermal fin rays can also inform the behavior, ecology, and developmental evolution of tetrapodomorph fishes. Here we use computed tomography to describe the dermal rays of the pectoral fins of three tetrapodomorph species: *Sauripterus taylori*, *Eusthenopteron foordi*, and *Tiktaalik roseae*. We find that in the lineage leading to crown group tetrapods, fin rays were simplified (segmentation and branching was lost), the fin web was reduced in size, and asymmetry evolved between dorsal and ventral hemitrichia. In tetrapodomorph pectoral fins, dorsal hemitrichia generally cover the endoskeleton to a greater degree than the ventral hemitrichia, indicative of dorsoventral asymmetries in the distribution of fin musculature. Notably, in *Tiktaalik*, dorsal hemitrichia cover the third and fourth mesomeres, while ventral hemitrichia are restricted distal to these elements, suggesting the presence of ventralized musculature at the fin tip, analogous to a fleshy palm. Additionally, in tetrapodomorph pectoral fins, dorsal and ventral hemitrichia differ in cross sectional area. *Eusthenopteron* dorsal hemitrichia are slightly larger than ventral hemitrichia, and the magnitude of difference is consistent between individuals of different sizes; while *Tiktaalik* dorsal hemitrichia are several times larger than ventral hemitrichia, and magnitude of asymmetry is greater in larger individuals. This indicates a transition from isometric to allometric scaling between the dorsal and ventral hemitrichia in elpistostegids. We argue that dermal fin ray evolution in tetrapodomorphs shows convergence with benthic actinopterygians and adaptation to substrate-based loading and prior to the origin of digits.

83-6 STILLER, AB*; STAUB, NL; Whitman College, Walla Walla, WA and Gonzaga Unviersity, Spokane, WA, Gonzaga University, Spokane, WA; *stilleab@whitman.edu*

Not a surprise: Female salamanders (plethodontid species Aneides ferreus) communicate to males during courtship as evidenced by courtship-like glands on their dorsum

The tail-straddling walk of plethodontid salamanders is a stereotypical courtship behavior to ensure spermatophore uptake by the female. With the recent description of the circular-tail-straddling walk in *Aneides ferreus*, it became clear that females are more actively participating in this courtship ritual than previously understood. We examined the tailbase region of both male and female *A. ferreus* for potential pheromone-producing glands (modified-granular glands) which have been described primarily in male salamanders. We identified these glands using histochemistry and morphology, in both males and females, on the dorsal and ventral surfaces of the tail. These glands are similar to the known pheromone-producing gland on the chin of males, the mental gland. They are positive for the periodic-acid Schiff test, have a granular secretory product, and have large secretory cells around the gland periphery. The presence of these modified granular glands is not sexually dimorphic, though not all females examined possessed them. The frequency is sexually dimorphic; males have more modified-granular glands on their dorsum than females do. No modified granular glands were identified on the dorsal tailbase region in females of the other species examined that perform the linear tail-straddling walk (*Aneides hardii*, *Aneides flavipunctatus*, and *Aneides lugubris*). The modified granular glands on the ventral tailbase region are thought to be involved in marking the substrate. Our results suggest that during the circular-tail-straddling-walk, the female is signaling to the male as well as vice-versa.

87-7 STINSON, HM*; MUKHERJEE, R; TYTELL, ED; SCHWALBE, MAB; Lake Forest College, Tufts University; *H.Stinson97@gmail.com*

Lateral line and visual systems in bluegill sunfish (Lepomis macrochirus) contribute to regaining stability in horizontal vortices

Fish encounter complex hydrodynamic environments while swimming and probably rely on multiple sensory systems to adjust their swimming and to remain stable in unsteady flows. It is unclear how the lateral line and vision contribute to a fish's ability to compensate for different types of unsteady flows, including horizontal vortices (like those shed by waterfalls, or over the top of rocks). Preliminary experiments showed that bluegill sunfish (*Lepomis macrochirus*) were stable in horizontal vortices with and without their lateral line and visual systems. Here, we challenged fish in a flow tank to more frequent horizontal vortices generated by a custom-made flapper and faster flow rates to continue testing the relative importance of these sensory systems in fish swimming. To test vision, fish were filmed under regular or infrared light and to test the lateral line system, fish were treated with cobalt chloride to deactivate this sensory modality. A fish was positioned behind the flapper (flapping frequency = 1, 2, or 3 Hz) while swimming at one of three speeds during each trial and recorded with three high-speed cameras to obtain the fish's position relative to the flapper over time. Overall, fish recovered quickly from the flapper action and differences in swimming movements were observed under the various flow and sensory conditions and will be discussed. Therefore, we continue to support that bluegill sunfish are relatively stable in horizontal vortices likely due to passive properties of their bodies, but sensory input from the lateral line and visual systems contribute to regaining stability after exposure to unsteady flows.

29-3 STINSON EASTERLING, CM*; SEIS, C; DEBAN, SM; Northwest University, University of South Florida; *charly.easterling@gmail.com*

Evidence of power amplification and thermal robustness in salamandrid feeding mechanisms

Tongue projection is often used by salamanders to feed on land. Many plethodontid salamanders are known for high-powered, thermally robust, ballistic tongue-projection; however, examples of similar feeding mechanisms in salamanders outside of the group are limited. Previously, we found that a distantly-related salamandrid, *Chioglossa lusitanica*, possesses a high-powered feeding mechanism with two distinct, ballistic movements. Here we continue our investigation into this highly specialized feeding mode by testing the thermal robustness of tongue projection in the salamandrids *Chioglossa* and *Salamandra salamandra*. High-speed imaging (3000 Hz) was used to capture feeding events over a 20-degree temperature range for both species. During both tongue projection and radial rotation (i.e. tongue pad flipping), *Chioglossa* continued to show evidence of an elastic mechanism, with tongue projection power exceeding 4000 W/kg, while radial rotation often reached over 2000 W/kg. High-powered projections were observed over the entire temperature range for *Chioglossa*. Projection performance decreased as temperature decreased, but was more thermally robust than retraction performance across all temperature ranges. Conversely, feeding performance in *Salamandra* was more strongly affected by low temperatures; tongue projection and retraction velocity, acceleration, and power were lower than those at higher temperature ranges. These results further support the hypothesis of convergent evolution elastically powered feeding mechanism in *Chioglossa* and plethodontid salamanders.

37-2 STOCKER, MR*; NESBITT, SJ; ANGIELCZYK, K; SIDOR, C; FORTNER, J; OLROYD, S; LUNGMUS, J; SMITH, R; Virginia Tech, Field Museum, University of Washington, Southern Methodist University, University of Chicago, University of the Witwatersrand; *stockerm@vt.edu*

A New, Small Arboreal Reptile from the Upper Permian of Tanzania

The Permo-Triassic mass extinction massively reorganized terrestrial tetrapod communities from the synapsid-dominated ecosystems of the late Permian to communities with more reptile diversity in the Early-Middle Triassic. The Ruhuhu Basin of Tanzania documents the latter part of this transition; however, only large pareiasaur parareptiles and a single specimen of the ?archosauromorph *Aenigmastropheus parringtoni* are the known reptiles from the upper Permian Usili Formation, despite decades of collecting. We report a new, unique reptile from the Usili Formation that may represent the oldest diapsid from Tanzania. CT data reveal densely packed and well-ossified, and apparently unduplicated bones, indicating that the specimen represents the remains of an individual likely preserved within a coprolite. This small specimen (estimated humeral length = 21 mm) includes articulated forelimbs and hindlimbs with a humerus with both ent- and ectepicondylar foramina and a distinct capitellum, elongated metapodials and phalanges, and curved and tapered unguals, suggesting an arboreal lifestyle. The combination of elongated caudal vertebrae, and morphology of the pes and the manus suggest that this amniote is likely a diapsid reptile; however, a diagnostic skull was not found in this specimen. Additionally, the articulated caudal vertebrae have elongated centra distinct from those of anomodont synapsids, such as the possibly arboreal Suminia from the late Permian of Russia, indicating an arboreal ecology for some small reptiles in the late Permian.

21-2 STRANG, CG*; BROWN, EK; SHERRY, DF; HAMPTON, RR; University of Western Ontario, Emory University; *cstrang@uwo.ca*

Memory systems in food-caching caching and non-caching birds

For birds that overwinter in north temperate zones, such as Black-capped Chickadees and Dark-eyed Juncos, keeping track of reliable long-term food resources is critical. Chickadees have an additional overwintering strategy of storing food in unique cache sites and locating them using memory. Animals and humans have multiple memory systems. While both chickadees and juncos are under selective pressure to remember reliable long-term spatial locations (habit memory), chickadees are under additional selective pressure for quickly forming and rapidly updating spatial memory for unique cache sites (one-trial memory). We conducted a series of touchscreen experiments to assess each species reliance on these two types of memory. Habit memories were experimentally established in trials in which photographic backgrounds were paired with spatial arrays in which the same location always rewarded. In other trials, birds were given one-trial memory tasks on different photographic backgrounds that required them to remember which location had been rewarded most recently. Both species showed high accuracy on these one-trial memory tests. On trials in which one-trial and habit memory were put in conflict, however, both species preferentially used habit memory. We hypothesized that photographic backgrounds provided a contextual cue that birds used to determine which memory system to use. In a further experiment, the same photographic backgrounds were used for both habit trials and one-trial memory trials, eliminating their utility as a contextual cue. This change in procedure increased the use of one-trial memory and decreased the use of habit memory on trials in which the two memory systems were in conflict. We discuss how ecology and context influence the use of memory systems in Black-capped Chickadees and Dark-eyed Juncos.

90-7 STORCH, JD*; HERNANDEZ, LP; The George Washington University, Washington, DC; *jdstorch@gwu.edu*

Constraining the Power Stroke of Premaxillary Protrusion: The Evolution of Diverse Cranial Musculature in Cypriniform Fishes

Cypriniform fishes comprise over 25% of the world's freshwater species. These fish exhibit a suite of morphological novelties--including premaxillary protrusion mediated by a sesamoid bone, a muscular palatal organ, and the loss of oral teeth--associated with feeding and occupy a variety of trophic niches. Diverse morphology within the trophic apparatus provides a biological model with which we can investigate the evolution of complex systems. Prey capture is effected by protrusion of the premaxilla. Does developmental integration across hard and soft tissue components of the protrusile mechanism constrain diversity of trophic morphology? We want to investigate the signal of constructional constraint on the pattern of morphological diversity of the A1 division of the adductor mandibula muscle in Cypriniformes. Here we present an experimental framework using modeling and simulation. Our interpretation of anatomical diversity in this element of the trophic apparatus through a functional lens informs a biomechanical model that can be parameterized to support simulation of linkages. Measuring the mechanical stress regime of a simulated linkage provides selection criteria that reflect the constraint of successful sesamoid bone formation. We use a novel extension of the phylomorphospace approach to calibrate these empirical estimates of theoretical morphospace. In this way we are able to test hypotheses of developmental constraint *in silico* that are less experimentally tractable *in situ*.

62-4 STRUBLE, MK*; GARDNER, J; GIBB, AC; Northern Arizona University, Montana State University; *strublemikayla@gmail.com*

Grasping Behavior in Birds Drives Pedal Adaptations

Birds use their feet for a large range of functions including grasping behaviors. Many perching, raptorial, and vertically clinging birds show shortened proximal phalanges in their feet. To test the relationship between grasping behavior and phalangeal proportions, we conducted Bayesian phylogenetic comparative analysis on about 200 bird species using phylogenetic ANCOVA and compared alternative models using a Bayesian Information Criterion to select the most-fitting model while penalizing by the number of additional parameters. The most well-supported model in our analysis finds that the lengths of proximal phalanges in raptors are significantly shorter than other birds, suggesting extreme grasping strength in birds is related to shortened proximal phalanges. We then investigated the biomechanical mechanism for this phenomenon. The flexor complex of the avian foot acts as a series of complex pulleys and levers. Theoretical modeling of this system predicts the reduction in phalangeal length increases the mechanical advantage of each phalange, but to test this principle in such a complex system, we designed a series of physical models created from CT-scanned and 3D printed bird feet rearticulated into biomimetic robotic models. These models confirm that proximal phalangeal shortening does not directly increase the pressure exerted by the talons, it instead increases the pressure exerted by the interdigital pads. Our models showed that a 50% decrease in phalangeal length increases the interdigital pressure by over 160% with the same muscular effort. This suggests shortenings proximal phalanges increases the strength of the core of the foot rather than the pressure exerted by the tips of the talons.

87-2 SU, GT*; DUDLEY, R; PAN, TY; ZHENG, MZ; PENG, LS; LI, QS; Beihang University and University of California, Berkeley, University of California, Berkeley, Beihang University, Beihang University, Beihang University and Xihua University; *pantianyu@buaa.edu.cn*

Maximum Aerodynamic Force Production by the Wandering Glider Dragonfly (Pantala Flavescens, Libellulidae)

Maximum aerodynamic force production is a parameter critical to extreme performance in volant taxa, and which may also be relevant to optimization of force production in micro air vehicles. Here, we describe a new method for measuring maximum force production in free-flying animals, and present associated data for the wandering glider dragonfly. Flight trajectories were repeatedly acquired from pull-up responses by insects dropped in mid-air with submaximal loads attached to the center of body mass. Forces were estimated from calculations of the maximum time-averaged acceleration through time, and multiple estimates were obtained per individual so as to statistically facilitate approximation of their maximum capacity through use of the Weibull distribution. On a group level, wandering glider dragonflies are capable of producing total aerodynamic force equal to ~4.4 times their own body weight, a value which significantly exceeds earlier estimates made for load-lifting dragonflies, and for other volant taxa in sustained vertical load-lifting experiments. Allometric analysis further indicates that, among individuals, maximum force production declined systematically with increased body mass.

134-7 SUMMERS, AP*; TRNSKI, T; HANNAM, S; CONWAY, KW; University of Washington, Auckland War Memorial Museum, Texas A and M; *fishguy@uw.edu*

A diversity of fishes that suck - New Zealand edition

Clingfish (Gobeisocidae) are small, shallow water fishes found in marine and freshwater environments. They are distinctive for having a suctorial disk on their belly made up of elements of the pectoral and pelvic girdles and fins. Work on one species, the Northern Clingfish (*Gobeisox maendricus*) has demonstrated the extreme tenacity of this disk on smooth and rough surfaces. Across the family this disk is variable in size and shape. There are double disks, disks with many papillae, and disks that appear small for the length of the fish. We report on the disk morphology and performance of 10 species of clingfish from New Zealand. Morphologically two groups stand out - rubble associated with relatively large disks and algae associated species with smaller disks. We tested fish on molds from six abrasive surfaces, from smooth to 120grit. The peak stress under the disk ranged from 50-100kpa. The theoretical maximum stress in our experimental design was 101kPa. It was possible to get performance data from fish as small as 70mg. Smaller fish could not stick to the roughest surfaces. The suctorial disk is a device that requires no living input. A dead fish will stick repeatedly with the same tenacity an arbitrary number of times. We made over 100 tests on one fish without degradation of attachment.

104-6 SUMMERS, AP*; MULLER, U; UW -Friday Harbor Labs, CSUF; *fishguy@uw.edu*

Ideas and initiatives for the two SICB journals

The editors of Integrative Comparative Biology and Integrative Organismal Biology will continue a dialog with members on issues of transparency, inclusion, diversity, and accessibility. The aim of this time slot will be to solicit opinion and guidance from the membership on these issues as they relate to our society's journals.

66-6 SUN, B-J; HUEBNER, C; TREIDEL, LA; CLARK, R; ROBERTS, KT; WILLIAMS, CM*; Chinese Academy of Sciences, University of California, Berkeley, Sienna College; *cmw@berkeley.edu*

Integrated behavioral and physiological strategies allow Gryllus lineaticeps crickets to fly on cool nights

Dispersal flight is an important component of life history strategies for many animals. For insects, the only ectotherms to have evolved powered flight, dispersal at night may present a challenge because low temperatures can limit physiological functions. *Gryllus lineaticeps* crickets have a wing polymorphism consisting of flight-capable (long wing; LW) and -incapable (short wing, SW) morphs. In the field, temperatures during the active period are frequently below the threshold for flight initiation. We test four non-exclusive hypotheses to determine the strategies nocturnal insects use to achieve flight: 1) behavioral thermoregulation to increase Tb; 2) pre-flight warm-up using muscular contractions; 3) resistance to heat loss; 4) modification of thermal performance curves to permit flight at low body temperature. Experiments on wild and lab-reared crickets showed that LW crickets had higher thermal preferences and field body temperatures than SW crickets. They performed wing-shaking prior to flight initiation, which further raised their body temperatures until they reached the threshold temperature for flight initiation. LW crickets had higher mass-specific metabolic rates and a greater resistance to passive cooling compared to SW crickets. Thus, we found support for all four hypotheses and conclude that LW crickets use a combination of behavioral and physiological strategies to facilitate nocturnal flight. Our study highlights the complexity and diversity of responses to variable thermal environments in ectotherms.

137-1 SUSTAITA, D*; FARABAUGH, S/M; BARTHMAN-THOMPSON, L; Department of Biological Sciences, California State University San Marcos, Institute for Conservation Research, San Diego Zoo Global, Suisun Marsh Unit, California Department of Fish and Wildlife, Stockton, CA 95206 USA; *dsustaita@csusm.edu*

Why morphology matters for management: the role of organismal form and function in wildlife conservation and management

Ecomorphologists and natural resource professionals often have different priorities, but share the common interest of advancing the state of understanding of the organisms they steward. Here we present snapshots of two case studies that illustrate the reciprocal benefits of in-depth morphofunctional analysis to address this joint cause. One study in collaboration with San Diego Zoo Global Institute for Conservation Research looks at the ontogeny of feeding performance in endangered San Clemente Loggerhead Shrikes. Here we address questions regarding how predatory proficiency relates to beak development, and when juveniles attain adult-levels of performance. This work is relevant to captive breeding efforts because it provides ways to quantify predatory performance, and an opportunity to assess whether juvenile feeding performance predicts post-release survival. A second case study in collaboration with the California Department of Fish and Wildlife examines the morphological basis to habitat use in the endangered salt marsh harvest mouse. Of particular interest is whether these mice possess specialized swimming and climbing capabilities that allow them to tolerate periods of tidal inundation. These data are useful for assessing the potential impacts of tidal restoration, because they shed light on how mice negotiate flooded habitats. Taken together, these studies provide new functional insights and metrics for species of conservation concern, which could ultimately aid in their preservation.

119-4 SWALLA, BJ*; FODOR, A; LOWE, EK; STOLFI, A; Friday Harbor Laboratories, University of Washington, Friday Harbor, WA 98250, Department of Biology, University of Washington, Seattle, WA 98125, School of Biological Sciences, Georgia Institute of Technology, Atlanta, GA, School of Biological Sciences, Georgia Institute of Technology, Atlanta, GA; *bjswalla@uw.edu*

Tailless Molgulid Ascidians express Larval Pseudogenes

Transcriptomic and genomic data offer exciting new approaches to examine the genetic networks underlying the origin and evolution of the chordate body plan. We study two closely related tunicate species with very divergent larval body plans—the tailed ascidian *Molgula oculata* and the tailless *M. occulta*. Tailed *M. oculata* embryos, like most solitary ascidians, have 40 notochord cells that are converged and extended in the center of the tail of the tadpole larvae. The larvae also have tail muscle cells flanking the notochord in the tail, and, in the head, an otolith, a gravity sensory organ with a single pigmented cell. The tailless *M. occulta* do not form a tail in their larval stage and lack the otolith, and the pigment cell associated with it. We have sequenced the genomes and analyzed developmental transcriptomes for both species and the hybrid embryos. Hybrid embryos made from the sperm of the tailed, *Molgula oculata* and the egg of the tailless *Molgula occulta* undergo convergence and extension of the notochord to form a short tail and, in some cases, also a pigmented otolith. We have shown that the muscle genes and tyrosinase pigment genes are pseudogenes in the tailless *M. occulta* species, but in some cases, the mutated transcripts are found in the transcriptome. We have also found examples where the tailless genes are intact, but show different expression levels in the hybrids, suggesting that there are changes in the cis regulation of the genes. We are continuing analyses of gene expression in the parental species and also in hybrid embryos in an effort to understand the evolution of the genetic networks necessary for tadpole larval development in ascidian embryos.

100-7 SWANSON, DL*; OBOIKOVITZ, P; University of South Dakota, Vermillion; *david.swanson@usd.edu*

Environmental Heterogeneity and Metabolic Flexibility in Horned Larks and House Sparrows: A Test of the Climatic Variability Hypothesis

The climatic variability hypothesis posits that physiological flexibility should be higher in organisms from more variable climates. Summit (Msum) and basal (BMR) metabolic rates are flexible traits and seasonal metabolic flexibility can be advantageous for small birds living in highly seasonal environments. Behavioral thermoregulation may reduce demand for seasonal metabolic flexibility, but favorable microclimates may be less available to some birds than others, depending on habitat. To investigate the relationship between seasonal variation in environmental temperatures and metabolic flexibility, we compared seasonal metabolic flexibility and microclimates (operative temperatures) of horned larks (*Eremophila alpestris*), which occupy open habitats, and house sparrows (*Passer domesticus*), which occupy more protected habitats, from South Dakota. We hypothesized greater seasonal variation in BMR, Msum, and operative temperatures for horned larks than for house sparrows. Winter daily average and minimum operative temperatures were similar for the two species' habitats, but including convection resulted in lower winter temperatures for lark habitats. Summer daily average and maximum operative temperatures were higher for lark habitats, even after incorporating convective heat loss. Both species demonstrated metabolic flexibility with higher Msum in winter and lower Msum in summer; however, the seasonal change for larks was 25% greater than in sparrows (39.4% vs. 31.4%). Significant seasonal variation in BMR occurred only for larks, with 92.5% higher BMR in winter than in summer. These results are consistent with the climatic variability hypothesis in that horned larks occupied habitats with more variable temperatures and showed greater seasonal metabolic flexibility.

118-4 SWIDERSKI, DL*; ZELDITCH, ML; University of Michigan, Ann Arbor; *dlswider@umich.edu*

An Incisor Runs Through It II. Evolutionary modularity of the squirrel mandible

If variational modularity explains how complex adaptations can evolve, it should predict the pattern of evolutionary modularity. The rodent mandible has long served as a classic example of variational modularity, but the prevailing hypothesis is of two "functional modules": the tooth-bearing front and muscle-bearing back. That is difficult to reconcile with the idea that the mammalian mandible can be modeled as a beam because a beam is not divisible into two functional complexes along its length. In addition, it raises the specter of functionally incompatible changes occurring in different regions. This hypothesis is even more difficult to reconcile with the rodent mandible because the incisor runs through the mandible, well past the boundary between the modules, and the masseteric muscle overlaps the border in the other direction. These anatomical relationships lead to the question: why would the front/back model fit so well, if it does? Analyses of mandibular shape changes in four major lineages of squirrels reveal evolutionary modularity in all clades consistent with the Front-Back model, which is consistently one of the best for variational modularity, although it missed the integration along the beam. For evolutionary modularity, models derived from mechanical principles, incorporating that integration of the beam and uniting muscle-bearing processes in a module consistent with their functional coupling, provide evidence of an even stronger modular signal, indicating they improve upon the Front-Back model. Thus, modular patterns of evolutionary change are partially aligned with the Front-Back model, but lineages differ in their deviations from it. Also, the most disparate are the least modular in their evolutionary changes.

7-7 SYKES, BE*; BALENGER, SL; University of Mississippi; *besykes@go.olemiss.edu*

Nest Microclimate Manipulation Affects Growth, Development, and Heat-shock Protein Production in the Eastern Bluebird (Sialia sialis)

Temperature is important to breeding birds, as the timing and success of reproduction are largely influenced by climatic conditions. Altricial nestlings, which hatch naked and unfeathered, do not begin independently thermoregulating until the later stages of their development. Nest microclimate has been shown to influence avian growth, however, little work has been done to examine whether excessive heat influences the production of protective molecules in birds after hatching. We manipulated the temperature in eastern bluebird nestboxes to examine if nestlings become stressed in response to heat, and how it affects their physiology, as well as whether feather-degrading ectoparasites are influenced by this increase in temperature. We found that nestlings exposed to elevated temperatures gained less mass over time relative to those that received the sham treatment, and were in worsening body condition over the course of their development. We also examined expression of circulating heat-shock protein 70 (HSP70) to determine if there were differential protective responses to heat. Feather-degrading bacterial loads were quantified to determine whether these ectoparasites thrive under a temperature optimum. Overall, this study will provide valuable insights into how within-nest temperature affects the development and physiology of altricial birds.

66-3 TALBOT, WA*; WOLF, BO; University of New Mexico; *wtalbot@unm.edu*

Sonoran desert bats show modest capacities for thermoregulation in the heat

In the Sonoran Desert, the radiant heat from highly absorbent surfaces carries the extreme heat of the day well into the night and, with climate change, nocturnal minimal temperatures have increased more than diurnal maxima. As these phenomena are expected to intensify, there is the potential to affect the available foraging time for nocturnal aerial insectivores. We examined the thermoregulatory capacity of six Sonoran Desert bats: pallid bat, *Antrozous pallidus*, big brown bat, *Eptesicus fuscus*, California myotis, *Myotis californicus*, western pipistrelle, *Parastrellus hesperus*, California leaf-nosed bat, *Macrotus californicus*, and Brazilian free-tailed bat, *Tadadarida brasiliensis*. We measured resting metabolic rates, body temperature, rates of evaporative water loss and thermal tolerance using flow-through respirometry. All species had relatively modest thermal tolerance limits (~40 &deg C) compared to nocturnal birds (~48-64 &deg C)and some nocturnal rodents. A limited capacity for evaporative heat loss and lthal body temperatures of ~43 &deg C appear to contribute to these differences in performance in the heat.

131-4 TALAL, S*; FARINGTON, R; HARRISON, JF; CEASE, AJ; Arizona State University, Tempe; *stav.talal@gmail.com*

Diet Preference and Requirements Shift Substantially with Age in the South American Locust (Schistocerca cancellata)

Generalist feeders often behaviorally regulate their food choice to achieve their preferred macronutrient ratios to enable maximal growth and survival. However, the vast majority of studies on the topic have examined only a small portion of animal ontogeny, and it is not clear whether preferred ingestion ratios of protein:carbohydrate (P:C) intake targets (IT) vary during development of insects and other animals. Locusts and grasshoppers have been extensively used as models to study P:C IT, and these have generally found that ITs during the final instars showed balanced or carbohydrate-biased ITs. To understand the nutritional requirements during ontogeny, we measured the IT of each instar of the South American Locust, *Schistocerca cancellata*. In addition, we recorded growth performance and survival of locusts reared on single artificial diets varying in P:C for the entire developmental period. Once each week we counted the number of individuals and weighed 20 randomly-selected individuals of each sex and diet treatment. In contrast to studies focused on only the final instar, across the entire development period, performance (assessed as mass gain, survival, and rate of development) was highest on protein-biased artificial diets. Most instars chose protein-biased diets while only the final juvenile instar and adults chose carbohydrate-biased diets. We conclude that both dietary preferences and macronutrient needs of *S. cancellata* change dramatically during ontogeny, and that studies of the final instar are inadequate to predict nutritional needs throughout development. Supported by NSF IOS-1826848 and BARD FI-575-2018.

101-4 TALBOTT, KM*; SOINI, HA; NOVOTNY, MV; WHITTAKER, D; HIGGINS, B; KETTERSON, ED; Indiana U. Dept. of Biology, Bloomington, IN, Indiana U. Pheromone Institute, Bloomington, IN, BEACON Center for the Study of Evolution in Action, Michigan State U., East Lansing, MI; *kmtalbot@iu.edu*

Does Haemosporidian infection status influence volatile composition of avian preen oil?

The volatile compounds in preen oil, a secretion of the avian uropygial gland, contributes to bird odor. The composition of these compounds has been shown to vary by species, population, individual, sex, and season. But what information does the odor blend contain? Using the dark-eyed junco as a model, we asked whether preen oil composition varies based on the presence and intensity of infection with avian malaria parasites. Haemosporidians are vector-transmitted blood parasites that cause malaria in vertebrate hosts. Mosquitoes that vector these parasites are known to prefer hosts with haemosporidian infections, but the mechanism behind this preference is unclear. If vectors use host odor to find preferred hosts, we predict that preen oil volatile composition of infected birds will vary from those of uninfected birds. In addition, if parasite growth induces a shift in host volatile composition, we predict that one or more volatile compounds should correlate in proportion with parasite load. To test these predictions, we collected preen oil and blood samples from non-migratory juncos in the Appalachian Mountains of Virginia during the early breeding season. We used gas chromatography-mass spectrometry to quantify the relative proportions of 15 volatile compounds in each bird's preen oil composition. Next, we analyzed DNA from blood samples through nested PCR and qPCR to identify haemosporidian infections and assess parasite loads. We will discuss differences in odor blend between infected and uninfected birds of both sexes, and the potential ecological relevance of these differences.

107-5 TANNER, RL*; GLEASON, LU; DOWD, WW; Washington State Univ., Sacramento State Univ.; *richelle.tanner@wsu.edu*
Pathway-Dependent Patterns of Gene and Protein Expression Variation Exposed by Thermal Stress in the Intertidal Mussel
Heterogeneous environments like the intertidal zone vary in environmental conditions over time and space, potentially leading to high inter-individual variation in physiology within a single population. We used gene and protein expression profiling in *Mytilus californianus* mussels exposed to five thermal regimes (4 field and 1 common garden) to better understand how thermal stress may expose or mask inter-individual variation. At a global level, thermal stress in the form of transplanting mussels to a high-intertidal site exposed high variation in global gene expression and tended to canalize global protein expression. We then asked whether thermal stress differentially affects variation in expression of individual genes and proteins within specific biochemical networks. We analyzed both canonical (*a priori*) biochemical pathways and highly interconnected clusters (i.e., empirical or *de novo* "pathways") generated from network co-expression analyses. We found 22 genes in six biochemical pathways that have opposing patterns of variation in gene and protein expression across treatments, and 18 genes that have opposing patterns of variation among treatments (for example, only high variation in ambient conditions). Using a dimension reduction analyses, we found expression was most canalized in common garden conditions across biochemical and empirical pathways. Taken together, these analyses suggest that the complexity of interactions between genes is reduced in protein expression, and the suite of genes with increased variation under thermal stress has limited overlap between transcript and protein expression.

140-1 TARASHANSKY, AJ; LI, P; XUE, Y; QUAKE, SR; WANG, B*; Stanford University; *wangbo@stanford.edu*
Cross-species mapping of cell type atlases identifies conservation and divergence in planarian and parasitic flatworms
Although all animals can heal wounds, only some are capable of regenerating from major tissue losses. Little is known about how and why most animals have lost the ability of whole-body regeneration. To answer these questions, we study two evolutionary cousins: the freshwater planarian, which is an immortal flatworm with unparalleled regenerative ability throughout the animal kingdom, and the parasitic flatworm schistosome, which infects hundreds of millions people and causes one of the most prevalent infectious diseases. Unlike planarians, schistosomes only have limited regenerative ability. Planarian regeneration relies on the pluripotent and tissue-specialized neoblasts to differentiate and produce all missing cell types under the guidance of a set of patterning signals expressed in muscle cells. To test if schistosomes have similar cell types, we have developed a single-cell transcriptomic analysis method (self-assembling manifolds mapping, SAMap) to construct a comprehensive cross-species comparative map of schistosome and planarian cell types, a task that has not been possible previously. This method has allowed us to identify schistosome cell types that are homologous to all planarian pluripotent and tissue-specialized neoblast populations, as well as muscle cells that express the patterning cues. Enabled by this cross-species comparison, We are now systematically examining the functions of these homologous stem cell populations and dissecting the gene circuits that control the fate of these cells.

59-5 TARRANT, AM*; BERGER, C; STEINBERG, DK; Woods Hole Oceanogr. Inst., Virginia Inst. Marine Sci.; *atarrant@whoi.edu*
Feast and Famine: Copepod metabolic condition during summer along the West Antarctic Peninsula
Within the surface waters of the West Antarctic Peninsula (WAP), copepods are the dominant component of the mesozooplankton during summer. Two of the most common species of large copepods exhibit different life history strategies. *Calanoides acutus* is predominantly herbivorous, stores lipids as wax esters, and overwinters in a dormant state. In contrast *Calanus propinquus* is more omnivorous, stores triglycerides, and often remains active during winter. During austral summer 2019, females of both species were sampled along the WAP continental shelf. Chlorophyll profiles and presumed food availability differed dramatically among sampling stations. Physiological condition of the field-sampled copepods is being assessed through transcriptional profiling and enzymatic activity assays. In addition, shipboard experiments were conducted in which copepods were either fed or starved for up to 9 days. Over the experimental period, citrate synthase activity decreased in the starved animals, consistent with metabolic depression and conservation of energetic reserves. Transcriptional profiling of corresponding experimental animals will provide insight into physiological adaptations to patchy food resources and context for interpreting observed patterns in the field.

67-3 TASSIA, MG*; DAVID, KT; HALANYCH, KM; Auburn University, Auburn, AL; *mgt0007@auburn.edu*
Innate immunity evolution in underrepresented metazoans and the implications when opting for similarity-metrics vs. hidden Markov models
In this study, we investigate the evolution of innate immunity signaling components among hemichordates and other underrepresented, and/or non-model, metazoans using a hidden Markov model (HMM)-based approach. Previous studies have shown that although the core innate immunity signaling pathways possess deep roots within Metazoa, the receptors responsible for host-pathogen interfacing exhibit dynamic diversification events within several bilaterian lineages such as annelids, bivalves, and echinoids. Like many signaling pathways, innate immunity-associated proteins fundamentally rely on domains of discrete characteristics – such as hydrophobic ligand binding, transmembrane helices, or catabolic activity. The identification and classification of any given protein's domain architecture is integral for inferring functional conservation/diversification among related proteins, particularly when investigating understudied, non-model taxa. In this study, we investigate three vital innate immunity protein families: Toll-like receptors, NOD-like receptors, and RIG-1-like receptors. The bioinformatic pipeline established here also principally addresses issues raised by database bias towards classic biomedical model systems (e.g., mouse, fly, and human). We show that HMM-based approaches, such as the one used in this study, provide a powerful alternative to similarity-based searches (e.g., BLAST); furthermore, the pipeline developed here can be applied to a large variety of protein families and taxa dependent upon the user's target protein and phylogenetic depth.

65-3 TAYLOR, LD*; WHITE, LD; University of California, Berkeley; *larry.taylor@berkeley.edu*

Building Collaborations with Local Community Colleges to Increase Diverse Students' Access to STEM Fields

The underrepresentation of certain groups in higher academia and STEM fields is directly contrasted by the overrepresentation of these same groups in U.S. community colleges. Relative to their peers at four-year institutions, community college students are much more likely to come from low-income households, are much more likely to identify as members of an underrepresented minority group, and are much more likely to be first-generation college students. Unfortunately, few community colleges offer access to research experiences or specialized biological disciplines, leaving diverse students less prepared to pursue these disciplines or scientific research later in their academic career. This creates an opportunity for museums and four-year institutions to partner with local community colleges to both enrich students' educational experience and increase accessibility to our fields. At the University of California Museum of Paleontology at UC Berkeley, we have developed a program which integrates custom-built, fossil-based laboratory class sessions into the course curricula of local community colleges. By enabling community college students to actively engage with the field of paleobiology and interact with students, researchers, and faculty mentors working in the field, we intend to create an environment where community college students may gain both interest in the field and confidence in their ability to pursue higher academia. We hope that we may help provide a blueprint by which other institutions can build avenues for local community college students to explore their interests and eventually bring their diverse backgrounds and perspectives into our fields.

93-1 TAYLOR, LD*; FINNEGAN, S; O'DEA, A; BRALOWER, TJ; University of California, Berkeley, Smithsonian Tropical Research Institute, Pennsylvania State University; *larry.taylor@berkeley.edu*

Isotopic Analysis of Fossil Coronulid Barnacles as a Means of Understanding Prehistoric Whale Migration

Migration is an integral feature of modern mysticete whale ecology, and the demands of migration may have played a key role in shaping mysticete evolutionary history. Constraining when migration became established and assessing how it has changed through time may yield valuable insight into the evolution of mysticete whales and the oceans in which they lived. However, there are currently few data which directly assess prehistoric mysticete migrations. Here we show that calcite 18O profiles of modern whale barnacles (coronulids) accurately reflect the known migration routes of their host whales. We then show that 18O profiles from well-preserved fossil coronulids exhibit trends and ranges similar to those of modern specimens, indicating that multiple Plio-Pleistocene whale populations of both the humpback and gray whale lineage were undertaking migrations of similar extent to those of the present day. We also find that Pleistocene whales congregating on the Pacific coast of Panama included individuals belonging to several different subpopulations, as the recovered 18O profiles indicate very different migratory paths. Continued work on this project is aimed at integrating fossil coronulid 18O profiles with paleoceanographic models and emerging proxies that can independently constrain seawater temperature and isotopic composition in order to more tightly constrain the migratory pathways of prehistoric mysticete whales.

122-2 TAYLOR, MS*; O'BRIEN, HD; GIGNAC, PM; Oklahoma State University Center for Health Sciences; *matthew.s.taylor@okstate.edu*

Shrinkage after swimming in iodine? Evaluating the use of hydrogel stabilization for reinforcing nervous tissues before iodine diffusion

As a soft-tissue imaging technique, diceCT (diffusible iodine-based contrast-enhanced computed tomography) offers outstanding opportunities for analyzing small neuroanatomical structures without requiring dissection. Recently, diceCT methods have been refined with respect to preserving, iodine-staining, and scanning neural tissue for visualization. Here, we add to the growing discussion of diceCT "best practices" by testing the efficacy of the STABILITY tissue stabilization protocol, in which samples are reinforced with hydrogel prior to iodine staining. One purported advantage of hydrogel is to limit tissue shrinkage that can occur when a specimen is exposed to high concentrations of iodine. However, infiltrating specimens with hydrogel adds substantial time and additional expenses to an experiment. Although seemingly intuitive, it is unclear if stabilization is a routinely necessary step to obtain satisfactory results. To evaluate the necessity of hydrogel stabilization, we obtained post-mortem brains of 18 juvenile Sprague Dawley rats from an unrelated drug addiction study, wherein some rats were exposed to high levels of morphine and others to a saline control. We applied the STABILITY protocol to half of the brains prior to iodine staining. Using microCT visualizations, we analyzed the two-dimensional shape of the corpus callosum at the mid-sagittal plane and found no significant differences in the structure of this brain region due to either drug treatment ($p = 0.16$) or tissue preservation technique ($p = 0.31$). These results suggest that the costs of hydrogel stabilization may not provide benefits for all neuroanatomical studies.

107-7 TEETS, NM*; DALRYMPLE, EG; HILLIS, MH; LEE, RE; DENLINGER, DL; University of Kentucky, Lexington, Miami University, Oxford, OH, Ohio State University, Columbus; *n.teets@uky.edu*

To Freeze or Not to Freeze: Cold Tolerance Strategies in an Antarctic Midge

For freeze-tolerant insects, internal ice formation presents additional challenges beyond cold *per se*, but few studies have directly compared freezing vs. supercooling at the molecular and physiological level. Here, we investigated molecular responses and physiological costs of freezing in the Antarctic midge, *Belgica antarctica*. In previous work, we demonstrated substantial costs to freezing in summer-acclimatized larvae, including mortality and tissue damage, reduced locomotion, and damage to proteins. In this talk, first we directly compare the physiological effects of freezing and supercooling in winter acclimatized larvae. Winter larvae survive freezing and supercooling equally well, and we observed no evidence of sublethal tissue damage in either condition. However, short-term freezing elicited higher expression of certain heat shock protein transcripts, suggesting a higher degree of cellular stress in frozen larvae. Biochemical responses were similar in both cold treatments, although frozen larvae tended to have lower levels of glycogen reserves, suggesting additional energetic costs to being frozen. In an ongoing transcriptomics study, we are directly comparing molecular responses to sublethal freezing and supercooling. Preliminary analyses indicate distinct molecular responses to each treatment, with supercooling eliciting a larger number of gene expression changes overall but freezing resulting in higher expression of stress-related proteins. Together, these studies will contribute towards identifying the precise molecular and physiological processes that are required to survive in the frozen state.

47-2 TEIXEIRA, RV; TITON, SCM; TITON JR, B; GOMES, FR; ASSIS, VR*; University of Sao Paulo; *v.regina.a@gmail.com*
Trace elements and amphibian's immunity - what can we expect?
Amphibians are animals that are closely associated with both aquatic and terrestrial habitats, what makes them vulnerable to different habitats modifications. Among those modifications, those caused by humans as fragmentation, introduction of emergent diseases, invasive species, and pollution can be highlighted as the most worrying. Pollution by trace elements can cause an impact in immune response of amphibians, depending on the amount and duration of exposure. The aim of this study was to evaluate the innate immunity of *Rhinella diptycha* toads at three sites with different contamination levels. Therefore, blood samples were collected to measure corticosterone plasma levels (CORT), neutrophil/lymphocyte ratio (NL) and plasma bacterial killing ability (BKA). Toads were subjected to a challenge with the mitogen phytohemagglutinin (PHA) followed by measurements of swelling response. Animals had organs collected (kidney, liver and spleen) to verify morphometric characteristics and bioaccumulation levels of trace elements specifically in the livers. The sites were divided in three levels of contamination, accordingly to the amount of trace elements found on the sediment, as follow: site 2 > site 1 > site 3. Toads from site 3 (the less contaminated) had higher levels of zinc on their livers, smaller kidneys, and larger spleens when compared to the other two sites. The toads did not presented difference among sites for CORT, NL or BKA, but toads from site 3 showed higher maximum swelling after PHA challenge. Although there is no statistical difference among sites on the main stress markers, CORT presented lower levels in toads living in the less contaminated site. These results indicate that animals living in more contaminated sites might present lower inflammatory response.

58-2 TEWS, VH*; BARNETT, AA; DeSales University, DeSales Univeristy; *vt7905@desales.edu*
Examining the Evolution of Epidermal Growth Factor (EGF) Pathway Ligands in Insects
The EGF pathway is a highly conserved and ubiquitously used cell signaling cascade in the development of many animals. In the highly studied Drosophila melanogaster, four ligands (vein, gurken, spitz and keren) are used to activate the pathway while one ligand (argos) is used to repress activation of the EGF pathway. An arthropod centered phylogenetic analysis showed that the genes which encode the ligands Vein and Argos were present in the last common ancestor of all arthropods. However, this analysis showed the genes encoding Gurken evolved in the last common ancestor of the Diptera, the clade which includes flies. In continuation of this research, evidence was provided showing the orthologues of spitz and keren are the result of multiple independent gene duplication events. In an attempt to determine the ancestral role of the spitz/keren gene during insect development, we used RNAi targeting the orthologues of the genes in two separate lineages, Orthoptera and Hemiptera. These lineages are represented by the cricket Gryllus bimaculatus and the milkweed bug Oncopeltus fasciatus respectively.

57-3 THAKER, M*; BATABYAL, A; AMDEKAR, M; Indian Institute of Science, Bangalore, India; *mthaker@iisc.ac.in*
Alternative strategies and the dynamism of color
Alternative social strategies in lizards are often correlated with distinct color forms that are fixed upon development. In the Indian rock agama, *Psammophilus dorsalis*, dynamic physiological color changes allow males to express alternative color patterns for courtship and aggression. These social colours of males (especially the courtship pattern), are conspicuous not only to conspecifics but also to predators, and thus impose a greater risk to males than non-social colors. To balance the predation risk of conspicuous colors with the benefits of social signalling, males switch in and out of color states within minutes. Given population differences in selection pressures, the intensity of color states differs between urban and rural populations, with associated differences in testosterone and corticosterone responses to social challenges. Overall, whole organismal shifts in phenotypic strategies that include hormone responsiveness and health indices, suggest that urban lizards have social coping styles that are reactive and not proactive.

108-3 THANDIACKAL, R*; LAUDER, GV; Harvard University; *rthandiackal@gmail.com*
Turning in Zebrafish: Measuring Body Pressure, Torque, and Work During Spontaneous Turns
Energetic efficiency has long been considered an important feature of routine animal behavior. In fluid environments, fish swim using body undulations to navigate and propel themselves forward, but direct measurement of work done by the body on the fluid has proven challenging. Moreover, fish often rely on unsteady maneuvers during tasks like navigation, feeding or predator evasion. Here we investigate spontaneous turns in zebrafish using a modified Particle Image Velocimetry (PIV) technique. The method is inspired by previous work on micro scale PIV and does not require a laser to record the movements of fluid particles in a specific 2D plane, but makes use of a narrow depth-of-field instead. We combine the obtained flow field measurements with pressure computations to estimate the interaction forces and the mechanical work done between the turning fish body and the fluid. Our results show that the majority of mechanical work is done by the body on the fluid and that energy is transferred to the water in two bursts. Our method allows quantification of the hydrodynamic cost of a turn and additionally provides information about how much each segment along the anterio-posterior body axis contributes to the energy transfer to the fluid. This method provides a rigorous way to quantify hydrodynamic mechanisms of fish swimming, and we expect that it could be valuable for future analysis of hydrodynamics in fish schools.

88-4 THOMAS, KN*; GOWER, DJ; BELL, RC; FUJITA, MK; SCHOTT, RK; STREICHER, JW; Natural History Museum, London, UK, Smithsonian National Museum of Natural History, Washington DC, USA, University of Texas at Arlington, USA, Smithsonian National Museum of Natural History, Washington DC, USA; *kate.thomas@nhm.ac.uk*

Ecological Correlates of Eye Size in Frogs and Toads

A typical frog may elicit the image of a small, leggy vertebrate with bulging eyes. However, relative eye size is highly variable among different species of frogs and toads (Amphibia: Anura). Larger eyes are costlier, but can improve visual performance, so variation in eye size has direct functional implications for vision. Research into major vertebrate groups such as birds, mammals, reptiles, and fishes has shown that ecological traits such as habitat, activity pattern, and behaviours associated with vision are often correlated with the relative sizes of eyes across species. However, anuran eye size has been understudied despite a stunning diversity of anuran ecologies and behaviours, and a single published study found no correlations between eye size and ecology in anurans. We measured anuran eye, cornea, and body sizes in 642 adult specimens representing 211 species and all 55 currently recognized families, and scored five natural history traits for all species from available literature in order to test for ecological correlates of relative eye size. Our data showed that frogs have large relative eye sizes compared to other vertebrates, and their eye diameters scale isometrically with the cube root of mass across species. Relative eye sizes were correlated with adult habitat and breeding ecology. Our study demonstrates the salient role that ecology has played in the evolution of anuran visual systems and highlights the importance of broad taxonomic sampling for detecting macroevolutionary patterns of trait evolution.

7-1 THOMAS, PA*; WHEELER, CR; PEELE, EE; PABST, DA; YOPAK, KE; KINSEY, ST; UNC-Wilmington, University of Massachusetts, Boston; *pat3805@uncw.edu*

Effects of Elevated Temperature on Muscle Development in Juvenile Epaulette Sharks, Hemiscyllium ocellatum

Temperature is known to affect embryogenesis and myogenesis in many fish species. Understanding effects of chronically elevated temperatures on fish muscle development is important for understanding potential effects of warming waters on individual organism health. Epaulette shark (*Hemiscyllium ocellatum*) eggs were reared and hatched,, for an average of 189 days at their normal mean environmental temperature (27 &degC) and 164 days at an elevated environmental temperature (31 &degC), and markers of muscle development as well as oxidative damage were evaluated. We measured muscle fiber size, nuclear density, and satellite cell density as markers of muscle development, heat shock protein expression (Hsp70), and protein and lipid oxidation (2,4-DNPH and 4-HNE, respectively) as markers of global oxidative damage. We found that elevated temperatures caused individuals to hatch earlier and to have smaller body sizes. Also, skeletal muscle growth was at an earlier stage compared to the normal temperature. Muscle fibers at both temperatures were similar in size and nuclear density, but satellite cell density was higher in the sharks raised at the elevated temperature ($p< 0.0001$). Fibers associated with satellite cells were significantly smaller at the elevated temperature than those at the normal temperature ($p<0.0001$). Generally, at the normal temperature, muscle fiber growth followed a linear trajectory with age post-hatch while muscle fiber growth under the elevated temperature showed greater variability with age. Total oxidative damage was higher at the elevated temperature ($p=0.004$) and increased with time ($p=0.010$), showing that these temperatures may induce oxidative stress which could be detrimental to organismal function and development.

S9-2 THOMPSON, CL*; WILLIAMS, SH; GLANDER, KE; TEAFORD, MF; VINYARD, CJ; Grand Valley State University, Ohio University Heritage College of Osteopathic Medicine, Duke University, Touro University College of Osteopathic Medicine, Northeast Ohio Medical University; *thompscy@gvsu.edu*

Getting Humans Off Monkeys' Backs: Can Ecophysiological Research Inform Primate Conservation and Habitat Management Efforts?

Wild primates face grave conservation challenges, with habitat loss and climate change predicted to cause mass extinctions in the coming decades. We apply knowledge from ecophysiology research to address management efforts in tropical mantled howling monkeys (*Alouatta palliata*). Body mass data spanning ~40 years shows that animals are heavier in riparian compared to drier upland habitats, and exhibit habitat- and sex-specific seasonal shifts in weight. Precipitation increased over these years, with male, but not female, weights also increasing. Collectively, we infer significant, sex-specific impacts of environmental conditions on howler morphology. Jaw-muscle electromyograms from free-ranging animals demonstrate howlers modulate bite size or other behavioral parameters in response to seasonal or longer-term changes in food material properties. Thermoregulation studies indicate that howlers buffer the direct effects of rising temperatures by using cool nighttime refugia and exploit spatial heterogeneity in their habitat to navigate changing thermal pressures. These lines of evidence cumulatively indicate howlers' use of physiological and behavioral mechanisms to adjust to temperature and rainfall changes. While habitat loss in the tropics is unlikely to abate, ensuring that forest fragments are suitably large with dynamic structures, as well as high connectivity between fragments, may aid howlers' survival.

24-2 THUBLIN, RN*; MOORE, PA; Bowling Green State University, University of Michigan Biological Station; *rthubli@bgsu.edu*

Crayfish self-medication: crayfish alter their feeding preferences based on parasite loads

Many organisms across the animal kingdom have been shown to utilize plants to self-medicate against parasite infection. Often organisms change their feeding preference based on the degree of parasite infection or impact of parasitism on their physiology. Changes in feeding preference can have large scale ecological impacts if the organism being studied is an ecosystem engineer. Crayfish, an established keystone species and ecosystem engineer, were placed in feeding trials with four different species of macrophytes. After feeding trials, the crayfish were dissected and parasite loads within the hepatopancreas were quantified by image-processing techniques. The percent of the hepatopancreas that was comprised of metacercariae of the parasite *Microphallus sp.* as well as the percentage that was melanized, the crayfish immune response to infection, were correlated to foraging choices and amounts. Crayfish did alter their feeding preferences and amount of consumption as a result of parasite load. In addition, different macrophyte consumption was correlated with the amount of melanization of the parasites. These results indicate that crayfish seem to be able to determine when they are parasitized by *Microphallus sp.* and make feeding decisions based on parasite presence. Establishing a change in feeding preference is the first step to determining if crayfish self-medicate when infected with *Microphallus sp.*

30-4 TIDSWELL, BK*; TYTELL, ED; Tufts University; *Ben.Tidswell@tufts.edu*

Using physical models to examine sensory coordination during fish schooling

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 need to use multiple sensory modalities to form and maintain their groupings. To investigate the role of the different senses involved in schooling behavior, we developed a simple robotic apparatus that could "swim" alongside groups of schooling giant danios Devario aequipinnatus. The system included an elastomer fish model, mounted on a rod, that oscillated its tail back and forth as it moved in a circular track. At certain swimming speeds and tail oscillation frequencies, the danios match speed with the model fish. Because of this, we can test how well the fish can match speed with the robot by perturbing the robot's velocity and quantifying how well the fish track the robot. We can also quantify the importance of different sensory modalities by testing schooling in the dark (so that vision is reduced), or with turbulence in the tank (so that the lateral line sense is reduced). This study will help us to explore how fish use different sensory systems to school in different environmental conditions and how they adapt to changes in the school.

94-1 TILMAN, FE; BAKKEN, GS*; O'KEEFE, JM; Indiana State University; *george.bakken@indstate.edu*

Assessing the Thermal Quality of Artificial Roosts for Conservation of Gregarious Bat Species

Bats (Order Chiroptera) are heavily impacted by habitat loss. Cavity and crevice roosting bats, >50% of bat species worldwide, are losing roost sites to deforestation. Artificial roosts might serve as alternatives, but comparative evaluations of different designs are few. Our comparisons of 3 common designs -- synthetic rubber "bark", a typical flat bat box, and a tall, square "rocket box" -- found Indiana bats (*Myotis sodalis*) strongly preferred the rocket box design. The proximate factors responsible for this preference are not clear, as the 3 designs differed in total volume, roosting surface area, odor, predator protection, and thermal characteristics. Neither do we know if preference translates into reproductive success. To better define causal factors, we exploit parallels with lizard studies to evaluate thermal conditions as related to variations in rocket box construction. Notably, solar radiation and rising warm air creates a vertical thermal gradient in the box. Thus, as do lizards in a gradient experiment, bats may move vertically to select a temperature. Further, many bat species are gregarious, so the amount of space (roosting surface area or volume) available within a temperature range is likely to be important. We compared microclimates in 20 designs differing in height, volume, heat storage, insulation, and air vents; boxes were closed to bats. Regressions to temperatures recorded at 3 heights were used to compute a thermal habitat suitability index established for reptile studies: the integrated product of space × time available at temperatures weighted by a physiological value factor. We found biologically significant differences among designs using ad hoc value factors. However, well-justified physiological and reproductive value factors are also needed.

S8-7 TINGLE, JL; University of California, Riverside; *jessica.tingle@email.ucr.edu*

Prevalence of Facultative Sidewinding Locomotion in Non-specialist Snake Species

Terrestrial vertebrates have repeatedly evolved elongate, limbless body plans, which require them to move using different types of locomotion than their limbed relatives do. All limbless terrestrial vertebrates can use lateral undulation, which involves side-to-side waves not unlike those used by swimming eels. After lateral undulation, concertina locomotion has been documented in the widest variety of limbless terrestrial taxa, including caecilians, amphisbaenians, snakes, and at least one lizard. Other types of limbless locomotion are less common and presumably more specialized. For example, we typically think of sidewinding as a gait that only a handful of very specialized species perform, mostly vipers from sandy desert environments. Some of these desert-dwelling vipers are so specialized that they only rarely use other types of locomotion. However, some non-viper species sidewind facultatively in particular circumstances, and a few may regularly sidewind under natural conditions. Numerous accounts report facultative sidewinding in species that more typically perform other types of locomotion. I have compiled these accounts, uncovering evidence that dozens of species perform sidewinding with varying proficiency under a variety of conditions. This compilation indicates that facultative sidewinding may be relatively widespread across several snake families.

104-1 TITON, SCM*; TITON JR, B; TEIXEIRA, RV; LIMA, AS; GARCIA NETO, PG; FERREIRA, LF; ASSIS, VR; GOMES, FR; MARKUS, RP; University of São Paulo, São Paulo, SP, Brazil, University Center Fundação Santo Andre, São Paulo, SP, Brazil; *stefannychristie@gmail.com*

Immune and hormonal circadian rhythms in captive bred Bullfrog (Lithobates catesbeianus)

Almost all physiological processes within the organism, including immune parameters and hormones, follow a circadian rhythm. These 24h-day fluctuations are often observed in free-living organisms. However, in anurans, little is known regarding hormonal and immune daily variations, particularly under captive bred conditions. The aim of this study was investigating the immune and hormonal circadian rhythms in captive bred Bullfrogs (*Lithobates catesbeianus*), a species often used as anuran model in laboratory studies. We measured plasma bacterial killing ability (BKA), blood phagocytosis (PP), neutrophil/lymphocyte ratio (NL), plasma corticosterone (CORT), testosterone (T) and melatonin (MEL) levels. Bullfrogs were kept individually in plastic containers in a controlled room (12:12 LD photoperiod [lights on 7am] and 21 ± 2°C) for 7 days. Animals were randomly sampled by cardiac puncture every 3h (5 animals at each time, 40 individuals total). BKA, CORT, T and MEL levels were determined from plasma. Our results show 24h-day rhythms for BKA, CORT, T and MEL, with increased values during the nighttime when compared with daytime for all those variables. Moreover, increased MEL levels were observed only late night (6h after lights turn off; ~ 1am). These results show captive bred Bullfrogs, under artificial conditions, exhibit immune and hormonal circadian rhythms with increased values associated with nighttime. PP and NL were performed from blood leukocytes, and are still being analyzed.

109-7 TITON JR., B*; TITON, SCM; ASSIS, VR; BARSOTTI, AMG; TEIXEIRA, RV; GOMES, FR; University of São Paulo, São Paulo, SP, Brazil; *zuza.bio@gmail.com*

Time-Related Inflammatory Response in Rhinella diptycha Toads

Inflammatory response is a complex process that relies on interactions between multiple endocrine and immune modulators and temporal course of inflammatory responses remains unexplored in amphibians. This study investigated changes in plasma corticosterone (CORT), testosterone (T) and melatonin (MEL) levels, bacterial killing ability (BKA), peritoneal leukocyte phagocytic activity (PP) and neutrophil:lymphocyte ratio (NLR) over time (1, 3, 6 and 18h post injection) following lipopolysaccharide (LPS) immune challenge in toads (*Rhinella diptycha*). Our prediction was that LPS should increase CORT, NLR, BKA and PP, with concomitant decrease in T and MEL. Regarding time related changes, CORT and PP should increase earlier, while BKA and NLR should present a delayed increase, whereas, MEL and T should present more pronounced decrease when those values are maximum in saline-treated toads. LPS induced inflammatory response. Increased CORT were more pronounced 6h and 18h post LPS injection, while MEL decreased independently of time. Although T was not affected by LPS injection, a decreasing trend was observed. Additionally, BKA and NLR also increased following LPS treatment but this effect was related with animal body condition. Individuals with a better body condition also displaying higher BKA and NLR values. Meanwhile, we observed increased PP 1h after LPS injection followed by a decrease thereafter. These results showed that toads respond to an immune challenge by modulating hormonal and immune parameters in a complex way, with effects observed from the first hour and extending for up to 18h following the stimulus.

S1-11 TODGHAM, AE; University of California Davis; *todgham@ucdavis.edu*

Two Plus Two Doesn't Equal Four: The Importance of Incorporating Realistic Environmental Variability in Understanding the Resilience of Antarctic Fishes to Climate Change

Although the Southern Ocean is experiencing some of the fastest rates of ocean change, few studies have explored how Antarctic fishes may be affected by co-occurring warming (OW) and acidification (OA). Organisms within these oceans may be some of the most vulnerable to environmental change, having evolved under stable conditions for millions of years. Early life stages are of particular concern as they are thought to be more sensitive to changes in climate-related variables than adults. Our research investigated the combined impacts of OA and OW on emerald rockcod (*Trematomus bernacchii*) juveniles and naked dragonfish (*Gymnodraco acuticeps*) embryos. Taking an integrative, multi-stressor approach combining metabolism, growth and development, cardiac performance, and behaviour, this research provides insight into the physiological plasticity of early life history stages of polar fishes to changing ocean conditions and how co-occurring stressors can interact synergistically to impact performance during early development. Our results provide evidence of stressor-induced energetic trade-offs in physiology and behaviour that may be an important mechanism leading to vulnerability of Antarctic fishes to future ocean change. Mechanisms and implications of non-linear interactions between multiple stressors will be discussed, with a focus on energy metabolism.

59-2 TOH, MWA*; LOBERT, GT; MORAN, AL; University of Hawai'i at Mānoa; *tohmw@hawaii.edu*

Thermal Sensitivity of Early Life History Stages of Antarctic Invertebrates

A paradigm of Antarctic biology is that Southern Ocean ectotherms are highly stenothermal, owing to millions of years of evolution under cold and thermally stable conditions. Given the predicted rapidity of climate change, it has become important to understand the response of polar ectotherms to rising temperatures. However, compared to adult stages, relatively little is known about the ecology of Antarctic invertebrate embryos and larvae or their sensitivity to temperature. For some Southern Ocean invertebrates, small increases in temperature have been shown to dramatically increase metabolic and developmental rates. Our study investigates the effect of rising temperatures on the development and metabolic performance of larvae from a range of Antarctic invertebrate taxa, including nudibranchs, echinoderms, and pycnogonids. Animals will be collected by SCUBA divers, and embryos and larvae will be assessed for thermal sensitivity using several indices of physiological performance. We will expose embryos and larvae to temperatures ranging from ambient to their experimentally determined critical temperatures and measure the effects of temperature on (1) heart rate, (2) oxygen consumption (as a proxy for metabolic rate), and (3) lethal temperature (as LT50). This will provide insight into the upper thermal limits of early stages of a diversity of Antarctic taxa, and potentially shed light on the mechanisms underlying failure at high temperatures. This research will be conducted starting in September 2019, at McMurdo Station, Antarctica. The goal of this study is to provide insight into the vulnerability – or resilience - of Antarctic ectotherms to rising ocean temperatures. Funded by NSF-OPP-1745130 to ALM.

S2-11 TOLLA, E; University of Glasgow; *2038705T@student.gla.ac.uk*

Rhythmic Neuroendocrine Expression of DNA Methyltransferase Enzymes in Seasonal Models

Seasonal reproduction is a strategy used by temperate zone animals to maximise the propagation of the species. The hypothalamus in birds and mammals is responsible for timing seasonal breeding. Seasonal epigenetic modifications in the hypothalamus have been demonstrated to regulate long-term timing of reproduction and energy balance in several photoperiodic species. Enzymes involved in *de novo* DNA methylation (Dnmt3a/b) are expressed within the hypothalamic-gonadal axis and exhibit seasonal variation. The objectives of my research were to investigate the effect of thyrotrophin-stimulating hormone (TSH) and triiodothyronine (T3) on the photoperiodic regulation of DNA methyltransferase enzyme expression. I tested the hypothesis that TSH or T3 in short day hamsters would stimulate hypothalamic expression in Siberian hamsters. Short winter-like day lengths induced a significant reduction in *Dnmt3a/b* in the hypothalamus. Male hamster hypothalamic *dnmt3a* nor *dnmt3b* expression did not vary in response to TSH. Then, I examined the impact of photoperiod and daily T3 injections or saline on hypothalamic *dnmt3a/b* expression and female reproductive physiology. SD photoperiods were observed to reduce body weight and uterine weight. Unlike previous reports in male hamsters, daily T3 injections in SD females were ineffective to stimulate gonadal recrudescence. Hypothalamic *Dnmt3a* and *dnmt3b* expression was reduced in SD, independent of T3. These data suggest that an alternative hormonal signal regulates *dnmt3a* and *dnmt3b* expression or that cyclical *dnmt3a/b* expression reflect an endogenous circannual timing system. Ongoing work seeks to identify whether long days reduce hypothalamic *dnmt3a/b* expression during the Japanese quail photoperiodic response. These data indicate that reduced neuroendocrine DNA methylation permits seasonal gonadal recrudescence.

107-6 TOMANEK, L.*; MAY, M.; VASQUEZ, C. ; TODGHAM, A.; California Polytechnic State University, San Luis Obispo, Univ. California, Davis; *ltomanek@calpoly.edu*

From Cellular Omics to Phenomics: The Role of Sirtuins in the Cellular Stress Response

The cause-and-effect chain of events across biological levels of organization is still an elusive target, challenging the integration of organismal systems. Several thioesters along metabolic pathways, e.g., acetyl-CoA, can interact with proteins to form post-translational modifications (PTMs), i.e., acyl-lysines. These PTMs affect protein function. NAD-dependent deacylases, i.e., sirtuins (SIRTs), can remove these PTMs, shift metabolism and activate an oxidative stress response (OSR), supporting cellular homeostasis during stress. We used a high temporal resolution time course to assess the effects of transcriptomic and proteomic changes on gill tissue and organismal phenotypes in response to heat stress and sirtuin inhibition in the intertidal mussel *Mytilus californianus*. Using proteomics, inhibitor studies showed that SIRTs affect molecular chaperones, oxidative stress proteins, metabolic enzymes and signaling proteins during heat stress. Additional inhibitor studies showed that food availability and heat stress during acclimation change how SIRTs affect multiple levels of organization: cells (ciliary activity), tissues (particle velocity and respiration rate of gill, siphon opening of mantle) and organismal performance (clearance rate) in *M. californianus*. Finally, these results are dependent on the circadian rhythm of mussels, in part because SIRT5 levels undergo circadian changes in abundance. The studies were funded by the NSF-grant IOS-1557500 to L. T. and A. T.

1-4 TOVAR, RU*; GIGNAC, PM; The University of Texas at Austin, Oklahoma State University Center for Health Sciences ; *rubenut@utexas.edu*

The Comparative Anatomy »of Degenerate Neural Structures Using Diffusible Iodine-based Contrast-enhanced Computed Tomography (diceCT)

The paedomorphic *Eurycea* salamander clade of Central Texas exemplifies a continuum of morphological characteristics associated with aquatic-subterranean living: the surface-dwelling Texas salamander (*E. neotenes*) exhibits typical optic anatomy and acuity; the intermediate Comal blind salamander (*E. tridentifera*) maintains reduced but non-functional eyes; and the obligate subterranean Texas blind salamander (*E. rathbuni*) has an incompletely developed optic system. Together this genus represents a transformation series of karst phenotypes and a potentially exemplar system for using comparative approaches to understanding vertebrate ocular evolution in the face of relaxed selective pressures. More than a century ago Eigenman described ocular histology in *E. rathbuni* adults as a focal troglodyte; yet, neither the extent of optic-nerve persistence in this taxon nor among its congeners has since been documented. In this study we employed gross and micro-scale imaging techniques to elucidate features of *Eurycea* optic anatomy with a particular interest in the central nervous system. Specimens from aforementioned taxa were fixed with 100% EtOH, contrast-enhanced with alcoholic iodine (I2E), micro-CT scanned, and digital reconstructed using 3D rendering software for comparison to histological sections. Here we report on the 3D, internal soft-tissue systems of the eye in each taxon, documenting habitat-specific configurations of optic musculature and neuroanatomy for the first time—including for *E. rathbuni*, which surprisingly appears to retain complete bilateral optic nerves even though it lacks the mid-line decussations associated with an optic chiasm.

132-1 TOWNSEND, JP*; GEMMEL, BJ; SUTHERLAND, KR; COLIN, SP; COSTELLO, JH; Providence College; Marine Biological Laboratory, University of South Florida, University of Oregon, Roger Williams University; Marine Biological Laboratory; *jptownsendii@gmail.com*

Ink release and swimming behavior in an oceanic ctenophore, Eurhamphaea vexilligera Gegenbaur, 1856

Of the upwards of 150 ctenophore species, the oceanic ctenophore Eurhamphaea vexilligera is peculiar in its release of a pigmented and bioluminescent ink, secreted from numerous small vesicles that line its comb rows. To date, in situ observations by SCUBA divers have proved the most fruitful method of observing these animals' natural behavior. We present the results of one such contemporary SCUBA-based observation of E. vexilligera, conducted in the Gulf Stream waters off the coast of Florida using high resolution photography and video. Utilizing underwater camera systems purpose-built for filming gelatinous zooplankton, we observed E. vexilligera ink release and swimming behavior in situ. From these data, we describe the timeline and mechanics E. vexilligera ink release in detail, as well as the animal's different swimming behaviors and resulting ink dispersal patterns. Our footage also revealed a previously-undescribed rolling swimming behavior, accompanied and possibly facilitated by a characteristic change in overall body shape. These observations provide further insight into the behavioral ecology of this unique ctenophore and may serve as the foundation for future kinematic studies.

44-2 TOXOPEUS, J*; DOWLE, EJ; RAGLAND, GJ; University of Colorado, Denver, CO, University of Otago, New Zealand; *jantina.toxopeus@ucdenver.edu*

Tracking Physiological Time: Timing and Duration of Cold Exposure Impacts Seasonal Life History Timing in a Temperate Insect

Many organisms time their development to ensure that a specific life stage coincides with a specific resource. Development rate of ectotherms varies with temperature, and therefore environmental temperature can affect life history timing. Many temperate insects overwinter in diapause, a dormant state of developmental arrest that can promote appropriate life history timing, mitigating the effects of temperature on development. However, this may not be the case for all insects, especially for non-photoperiodic insects, whose diapause is not regulated by daylength. The apple maggot fly *Rhagoletis pomonella* spends most of the year as a pupa in diapause, eclosing as an adult in late summer to lay its eggs in the fruits of its host plants. However, *R. pomonella* has a surprisingly flexible and dynamic diapause program, and can terminate diapause without any chilling or photoperiodic cues. *R. pomonella* is therefore an interesting model to study how non-photoperiodic insects regulate the timing of diapause termination, and the role of temperature in this regulation. To test the thermal sensitivity of the diapause program, we collected diapause *R. pomonella* pupae from hawthorn fruits in Denver, CO, and exposed them to differing lengths of winter conditions (4 °C) at different times during their pupal development. We then measured time to eclosion after transfer to summer conditions (21 °C). The impact of low temperatures on eclosion varied with both the timing and length of winter, suggesting that the thermal sensitivity of diapause development changes with age. This study challenges our understanding of how insects "keep track of" physiological time in diapause.

49-3 TRACY, CR*; MCWHORTER, TJ; University of California Riverside Boyd Deep Canyon Reserve, University of Adelaide Roseworthy; *christopher.tracy@ucr.edu*
Paracellular absorption in the slow(er) lane: a brief review of reptilian paracellular nutrient absorption
Some mammals and birds rely on passive, paracellular absorption of small, water-soluble nutrients (e.g. small carbohydrates) as a significant component of overall absorption of those nutrients. This is particularly important in small, flying mammals and birds, possibly as a means to fuel high metabolic demands despite small guts and fast digesta passage. But how important is paracellular absorption of those same nutrients for low metabolic rate taxa like reptiles? Our studies on herbivorous lizards and crocodilians suggest that paracellular nutrient absorption in these low metabolic demand vertebrates represents a relatively small, but significant proportion of total absorption, particularly in younger animals whose rapid growth may increase metabolic demands. This appears to support the hypothesis that paracellular absorption provides a low-cost source of additional energy for some species or life stages. At this time, paracellular absorption has been measured only in a few ectothermic species, and there have been few studies of ontogeny of paracellular absorption, so many questions about patterns in reptilian paracellular absorption remain unanswered

65-5 TRAN, MV*; MILLER, A; ODAKA, Y; OWEN, P; WILSON, K; University of Cincinnati Blue Ash College; *tranmk@uc.edu*
Designing Multifaceted Research Experiences for Undergraduates in Integrative Biology
Undergraduate research is a way for students to build important skillsets and develop interpersonal connections with fellow students and faculty. Practically speaking, undergraduates often seek research experiences as a way to explore various topics and identify the topics that they find most interesting. Thus, the firsthand experience gained by participating in undergraduate research can be used to help students make more informed decisions regarding the their educational and career paths. The biological sciences are comprised of numerous subfields in which students can specialize and therefore a major goal of undergraduate research experiences in biology should be to maximize the number of subfields to which students are exposed. However, finding projects and study systems that accomplish this goal within a single research experience is often difficult. This presentation will focus on the development of an annual summer research experience for freshman and sophomore undergraduates that provides student with experiences integrating various biological subdisciplines into a single project. Using a single study species, we designed student research projects that allowed students to test hypotheses related to ecology, behavior, microbiology, and molecular biology so students could better understand how each of these subfields contributes to our understanding of biology as a whole. Students learned both field and laboratory techniques through interaction with faculty with different areas of expertise in biology. This presentation will describe the process of creating these research experiences and outline both the successes and challenges of the project over the initial two years of implementation.

40-4 TRAVIS, KG*; KAWANO, SM; California State Uni., Long Beach, George Washington Uni.; *kevin.travis@student.csulb.edu*
Comparative biomechanics of submerged and emerged walking in the epaulette shark (Hemiscyllium ocellatum)
Epaulette sharks (*Hemiscyllium ocellatum*) are benthic fishes that commonly use a tetrapod-like "walking-trot" gait to move along the substrate and will occasionally emerge out of water to navigate reef flats. Given these characteristics, epaulette sharks have been considered a functional analog for tetrapodomorph fishes and may exhibit similar locomotor biomechanics as living salamanders (a common modern analog for early tetrapods). This study aims to broaden analyses of the locomotor biomechanics of epaulette sharks while fully submerged vs. partially emerged to allow for more direct comparisons to published work on salamander locomotion. We collected 3D kinematics of the paired fins between both environmental conditions while simultaneously obtaining 3D ground reaction forces (GRFs) from the fins. Subadult sharks were recorded under submerged (n=3) and partially emerged (n=2) conditions with two high-speed video cameras (200 fps) while individuals moved along a waterproof 3D force plate. Preliminary results from a single individual suggest that the average maximum protraction angle of the pectoral fins was higher when partially emerged compared to fully submerged while the maximum protraction of the pelvic fins remained relatively consistent. Additional analyses to compare the GRFs between paired fins and environmental conditions are ongoing and would yield a more comprehensive evaluation of the functional role of paired fins during aquatic and terrestrial locomotion. Comparisons of these results to salamander locomotor biomechanics would then enable quantitative analyses on the functional consequences of using fins versus limbs for a walking-trot gait, potentially providing insights on the biomechanical limitations of moving onto land.

2-5 TREIDEL, LA*; CLARK, RM; WILLIAMS, CM; UC Berkeley, Sienna College; *lisa.treidel@berkeley.edu*
Females pay the price: high costs of reproduction dictate sensitivity to diet quality in adult crickets
Primary productivity and thus food quality are predicted to fluctuate along with changing global climates. Organismal performance and life history investments are limited by suboptimal diets, unless feeding behavior is altered to compensate. Further, nutritional demands of life history traits differ. We hypothesized that optimal diets should shift through ontogeny along with investment in life history and predicted that behavioral responses and performance consequences of imbalanced diets will change concordant with life history demands. Within populations of the wing polymorphic cricket *Gryllus lineaticeps*, alternative development trajectories produce adult morphs that specialize in either dispersal or reproduction. We characterized dietary preferences and compensatory feeding strategies on imbalanced diets, by feeding last instar and adult crickets one of three isocaloric diet treatments: 1) protein-biased diet (2P:1C), 2) carb-biased diet (1P:4C), or 3) both diets (choice). As last instars, dispersal morphs needed to consume more food to support muscle development, and met this higher caloric requirement irrespective of diet macronutrient content. Males did not alter their feeding behavior across life stages. In contrast, females selected a more protein-biased diet and shifted their regulatory strategy to avoid overconsuming excess macronutrients on imbalanced diets as adults. Consequently, adult females incurred large caloric and protein deficits on the carb-biased diet, which in turn constrained reproductive investment and resulted in a reduction of ovary size and energy provisioning. These findings suggest that when physiological demands are high, behavioral adjustments do not fully offset costs of imbalanced diets, leaving specific individuals more sensitive to fluctuations in food quality.

49-1 TREVELLINE, BK; MARTíNEZ-MOTA, R; DERTING, T; DARRACQ, A; PASCH, B; DEARING, MD; KOHL, KD*; Univ. of Pittsburgh, Univ. of Utah, Murray State Univ. , Murray State Univ. , Northern Arizona Univ.; *kevin.d.kohl@gmail.com*

Nutrient manipulation differentially affects microbiome structure and host physiology in rodents with distinct dietary niches

Mammals must extract sufficient energy and nutrients from their diets for survival and reproduction. The digestive system and its resident gut microbiota are highly dynamic and responsive to diet, likely aiding in the maintenance of optimal digestion. However, studies investigating microbial and physiological responses to diet are typically conducted on a single species. Therefore, we have poor understanding of how the flexibility of the digestive system and gut microbiome structure varies across species. We conducted feeding trials with three species of rodents with distinct dietary niches: montane voles (*Microtus montanus*, herbivorous), white-footed mice (*Peromyscus leucopus*, omnivorous), and southern grasshopper mice (*Onychomys torridus*, insectivorous). Rodents were fed four different diets varying in their concentrations of fiber and protein for a period of five weeks. Rodents were dissected for measurements of gut morphology, and gut content samples were collected to inventory microbial communities via 16S rRNA sequencing. We found that several aspects of gut anatomy exhibited species-specific responses to diet. For example, small intestinal length showed no changes in voles, while in white-footed mice it increased in length in response to high fiber diets, and in grasshopper mice it increased in length in response to low protein diets. Similarly, the gut microbiota exhibited species-specific responses to diet. These data suggest that the flexibility of the digestive system and gut microbiota may be adapted to species-specific dietary niches.

102-3 TREVELLINE, BK*; MAIER, M; MARTINEZ-MOTA, R; DERTING, T; PASCH, B; DEARING, MD; KOHL, KD; Univ. of Pittsburgh, Univ. of Utah, Murray State Univ., Northern Arizona Univ., Univ. of Utah; *brian.trevelline@gmail.com*

Investigating the mechanisms of diet-induced metabolic depression in wild rodents

Many animals can lower their metabolic rate to conserve energy during changes in diet. This phenomenon is widespread across vertebrates, but the responsible mechanisms are not well understood. It is thought that animals achieve a hypometabolic state by reducing the mass of energetically-costly organs, but reduced mitochondrial activity could also play a role. We assessed the impact of diet on digestive physiology and metabolism in three species of rodents with different natural diets: grasshopper mice (*Onychomys torridus*; insectivore), white-footed mice (*Peromyscus leucopus*; omnivore), and montane voles (*Microtus montanus*; herbivore). Rodents were placed on either a high-fiber (37%) or low-fiber (12%) diet for 5 weeks, after which we measured resting metabolic rates via open-flow respirometry and weighed energetically-costly tissues, such as heart, gut, liver, and kidney. *O. torridus* fed high-fiber diets had significantly reduced metabolic rate, but *P. leucopus* and *M. montanus* did not. Interestingly, *O. torridus* on high-fiber diets exhibited greater gut masses and, opposite of our expected result, larger kidney masses. *P. leucopus* and *M. montanus* had significantly larger kidneys on high-fiber diets. Further, *O. torridus* on high-fiber diets exhibited higher mass-specific mitochondrial activity (measured by citrate synthase activity) in liver tissue, despite no significant differences in liver masses. These results suggest that rodents with different natural diets employ divergent mechanisms to compensate for sub-optimal diets, and that metabolic depression involves more than a reduction in organ size.

S3-7 TUCKER, A. S.; King's College London; *abigail.tucker@kcl.ac.uk*

Developmental basis of tooth regeneration

During evolution of mammals there has been a move towards a reduction in the number of times teeth are replaced over an animal's life-time. Most mammals have two sets of teeth (diphyodont), while most reptiles have continuous replacement (polyphyodont). This shift to reduced numbers of replacements is thought to have been driven by an increase in tooth shape complexity together with the advent of tooth occlusion. Therefore there appears to be an evolutionary trade off between tooth number and tooth complexity. Although two sets of teeth is the norm for mammals (deciduous teeth followed by permanent teeth), a number of mammals have reduced the number even further and have only one set of teeth (monophyodont), or a mixed dentition where some teeth in the jaw replace while others do not. This condition allows for investigation into the mechanisms that determine whether to replace or not within a single animal. This talk aims to understand how the number of replacement teeth is controlled using a comparative evodevo approach. What signals stop further tooth development in mammals? How do teeth influence the development of their replacements? Can extra generations be generated? The research takes advantage of a number of model and non-model species, encompassing a variety of replacement patterns (monophyodont, diphyodont, polyphyodont). The findings shed light on the potential to generate additional teeth, both from a zoological and biomedical perspective.

3-7 TUCKER, E L*; HSIEH, S T; Temple University, Philadelphia, PA; *liz.tucker@temple.edu*

Leg Length, Not Stiffness, Allows Bipedal Lizards To Navigate Drops

Natural terrain varies enormously in surface properties and contour; yet animals are able to move rapidly over these surfaces with apparent ease. Much is known about compensatory strategies of bipedal parasagittal and crouched runners over perturbations. For example, guinea fowl have been shown to lengthen their legs over sudden drops in terrain, whereas humans tend to change the stiffness of their limbs to compensate for drops, obstacles and changes in surface compliance. In contrast, dogs and cockroaches do not change their limb stiffness. Little is known, however, about how bipedal sprawled runners contend with perturbations and why such a diversity of strategies might exist. We ran 4 basilisk lizards (*Basiliscus vittatus*) over flat terrain (control) as well as drops of 40% their leg length. Basilisks were able to accomplish this task without any detriment to their running speed ($p = 0.962$). In general, they shortened their stride ($p = 0.0025$), while keeping stride frequency and duty factor constant. Lizards landed in the drop with a more upright body angle, touchdown angle and tail pitch while using a wider step than when unperturbed ($p < 0.05$). They also straightened their leg ($p = 0.0227$) but did not stiffen it. Lizards reached intermediate or control level values of tail pitch, body angle and touchdown angle by the next step. This response is very similar to the that used by guineafowl, for which their stability has been associated with the crouched limb posture. We propose that the sprawled, crouched posture found among many vertebrates and invertebrates can potentially convey greater locomotor stability for a similar reason—the ability to lengthen the limb can compensate for unexpected changes in surface contour.

133-2 TUNE, TC*; MA, W; IRVING, T; SPONBERG, S; Georgia Tech, Illinois Institute of Technology; *ttune3@gatech.edu*

X-Ray Diffraction of Synchronous Flight Muscle Reveals Thick Filament Force-Length Hysteresis Varies With Muscle Function

The energetic and functional versatility of muscle at the macroscopic level depends on the collective action of myosin motors in the contractile lattice. For example, myosin heads on thick filaments are out of register with actin binding sites, which limits crossbridge binding. However, due to compliance in myofilaments, filament strain change alters actin-myosin kinetics facilitating crossbridge cooperativity. Recent work in isometric active and passive muscle shows that thick filament strain at the sarcomere level has a nonlinear relationship with whole muscle force. However we do not know if this relationship holds under dynamic conditions. If not, then the dynamics of strain in the filaments could help shape work production in an intact muscle. To see how force and thick filament strain are related dynamically, we performed work loops at different phases of activation on isolated *Manduca sexta* flight (DLM) muscle with simultaneous time-resolved x-ray diffraction. Consistent with earlier results, we found that the thick filament underwent strain changes of .2+/-.1% and the overall elastic response was similar to that of vertebrate muscle. However the relationship between thick filament strain and force during the course of the work loop was hysteretic, with the difference in thick filament strain at the same force at different points in the work loop cycle being between 30 to 60% of the total amplitude. Taking into account potential contributions of non-filament based passive forces (e.g. extracellular matrix) could not account for the hysteresis. Changing the phase of activation modulates the hysteresis with *in vivo* conditions produce only half that of peak negative power conditions. Taken together these results mean that there is not a one-to-one relationship between myofilament strain and muscle force.

76-4 TURNER, ML*; GATESY, SM; Brown University; *morgan_turner@brown.edu*

Looking inside the sole: intermetatarsal mobility in the American alligator

Feet mediate animal-substrate interactions across an animal's entire range of limb poses used in life. Despite its importance, the foot is typically either ignored or treated as a "black box"—an anatomically complex set of visually obscured components that are difficult to simulate. The most dominant skeletal elements are the metatarsals, the 'bones of the sole.' In plantigrade animals, intermetatarsal mobility offers the potential for active reconfiguration within the foot itself. Using marker-based XROMM, we measured metatarsal kinematics in three juvenile American alligators (*Alligator mississippiensis*) across their locomotor and maneuvering repertoire on flat surfaces. Alligators are capable of postural extremes—from a belly sprawl to a high walk—and the foot is flexible enough to accommodate these diverse poses. Initial results reveal: 1) Regardless of limb placement, the metatarsals conform to the ground to maintain fully plantigrade contact throughout most of stance. Coordinated intermetatarsal motion adapts foot shape based on phase, spreading in stance up to 200% of the most compressed configuration during swing. 2) Intermetatarsal mobility contributes significantly to everted and inverted foot poses. Alligators predominantly inverted the pes; up to 40 degrees of inversion-eversion was measured, whereas only 10 degrees of ab-adduction was found. Continuing work will put intermetatarsal mobility in context of crural, pelvic, and digital kinematics, with the aim to understand the inner workings of the pedal "black box" and how it contributes to animal locomotion.

41-2 TYLAN, C*; LANGKILDE, T; The Pennsylvania State University; *clh319@psu.edu*

Immune Function Changes in Response to Consumption of and Stings from Fire Ants, an Invasive Predator and Prey of Native Lizards

Native ecosystems have been exposed to alterations from invasive species for decades, and the spread of non-native species is likely to continue in the future. Therefore it is important to understand the effects invasive species have on the animals in ecosystems into which they have been introduced. An excellent model system for addressing these questions is that of the eastern fence lizard (*Sceloporus undulatus*), which has been dealing with invasive stinging fire ants (*Solenopsis invicta*) for over 70 years. The presence of these invasive, predatory fire ants at a site has resulted in a number of morphological, behavioral, and physiological changes in the native fence lizards. This includes changes to their immune functions, decreasing some, while increasing or having no effect on others, as compared to lizards from ecologically similar sites which are not yet invaded by fire ants. We seek to discover if any of these immune changes are stimulated in lizards naïve to fire ants by direct exposure to fire ants, either through consumption of the ants, or by the ants stinging the lizards. These are both common routes of fire ant exposure in fence lizards, as the ants are both predator and prey, envenomating lizards via stings, but are also a frequent lizard food source. Understanding what changes in immunity are caused directly by exposure to fire ants, as opposed to evolved over time, will contribute to our understanding of how native species adapt to the presence of invasive species, and how quickly this can occur.

115-1 UEHLING, JJ*; INJAIAN, AS; TAFF, CC; WINKLER, DW; VITOUSEK, MN; Cornell Univ., Cellular Tracking Technologies; *jju8@cornell.edu*

The relationship between glucocorticoids and movement behavior during breeding in a free-living passerine

Movement patterns have wide-ranging effects on survival and population trends, and can greatly differ between individuals of the same species. However, we still do not understand the full suite of factors and mechanisms that generate differences in movement behavior. Hormones likely influence movement behavior, but their complete role is unclear. Glucocorticoid hormones (GCs) may contribute to vertebrate movement decisions; previous studies have demonstrated connections between GCs and movement during vertebrates' breeding seasons. Here, we examine the relationship between GC expression, movement behavior (geographic space use, distance travelled) and parental provisioning of offspring in breeding tree swallows (*Tachycineta bicolor*). We ask whether baseline corticosterone (CORT, the avian GC) predicts female swallows' fine-scale movement patterns and nestling provisioning rates, and if variation in these behaviors affects fitness (i.e. fledging success). To monitor movement behavior, we used two methods: solar-powered radio tags ("life tags"), which transmit unique identifying codes to an array of receivers across the breeding site; and a network of RFID boards, which record nest box visitation patterns. Because higher CORT tends to be associated with greater activity, we predicted that birds with higher baseline CORT would use larger geographic spaces for foraging, would travel farther, and would provision their nestlings more frequently. If our results show that CORT levels relate to movement and provisioning patterns, our findings would shed light on the role of GCs in coordinating movement, and how these movements relate to fitness outcomes.

88-1 UHRHAN, MJ*; FABIAN, JM; SIWANOWICZ, I; LIN, HT; Imperial College London, UK, HHMI Janelia Research Campus, Ashburn, VA USA; *myriam.uhrhan18@imperial.ac.uk*
Mechanosensors on Dragonfly Wings for sensing Aeroelasticity
Unlike wings of vertebrates, insect wings can only be actuated and controlled at the wing base. All wing deformations are results of passive interactions between aerodynamic loading and wing structural mechanics. This property of the wing is called aeroelasticity. To control and monitor such a complex system, insects have evolved an assortment of mechanosensors on the wing veins. It is not known, however, what and how each wing sensor captures information to support flight control. Dragonflies were the first insects to take flight over 300 million years ago, and remain the top flier in the insect world. Not surprisingly, their wings have significantly more mechanosensors than other insects' wings. Identifying the positioning and function of each type of sensor in the dragonfly wings is likely to reveal the key to aeroelastic sensing. We combined different imaging techniques to quantify the distribution of wing sensors and identified a novel sensor type. Punctuating the major wing veins, this mechanosensory consists of one bristle and one curious bump structure. To gain insight into how this sensor might function to detect flight-relevant forces, we modelled the interactions between sensors and surrounding airflow. Our simulations show that the bump filters out airflow in spanwise direction and that the aerodynamic forces acting on the sensor in chordwise direction differ with varying flight velocity. Thus, we speculate that the sensor location on the ridges of the wing veins enables the sensor to detect changes in the surrounding chordwise airflow.

25-2 URCA, T*; RIBAK, G; Tel-Aviv University, Tel-Aviv, Israel; *TomerUrca@gmail.com*
The Effect of Body Mass on Long-Distance Flight Efficiency in a Wood Boring Beetle, the 'Mango Stem Borer', Batocera Rufomaculata.
The Mango stem-borer, Batocera Rufomaculata, is an invasive species accidently introduced into Israel in the early 1950's and is one of its largest beetle species. Females lay eggs in the stems of Ficus trees and the boring larvae tunnel through the stem causing substantial damage to the host tree before emerging as flying adult. Adult beetles may differ in body mass 7-folds (1 - 7 gr) as a direct result of food availability and quality during larval growth. Research conducted at our lab has shown that smaller beetles, that developed on a poor diet, have higher long-distance flight endurance compared to large beetles, that developed on a richer diet, thus suggesting that smaller beetles are more efficient flyers. The physiological and biomechanical mechanisms increasing the flight efficiency of smaller beetles are currently unknown. Here, we examined the wingbeat kinematics of small and large beetles flying tethered in a wind-tunnel under increasing wind speed conditions. Flapping kinematics were extracted using two high-speed cameras and a set of two force transducers connected to the tether arm measured the forces exerted by the beetle during flight. Smaller beetles showed a preference for flight at lower wind speed. Nevertheless, the smaller beetles generated more lift per body mass than larger beetles at the preferred speed of larger beetles. Furthermore, the aerodynamic power per lift was lower in the smaller beetles indicating their higher flight efficiency. Measurements on revolving beetle wings have shown that larger ones require a higher power input/lift than smaller ones. This data suggests that smaller beetles possess elevated flight capabilities facilitating their dispersal from the less favorable environments in which they developed.

5-6 USHERWOOD, JR; The Royal Veterinary College, University of London; *jusherwood@rvc.ac.uk*
The possibility of zero-work gaits in sprawled and parasagittal quadrupeds: insights from linkages of the industrial revolution
Animal legs are diverse, complex and perform many roles. One defining requirement of legs is to facilitate terrestrial travel with some degree of economy. This could, theoretically, be achieved without loss of mechanical energy if the body could take a continuous horizontal path supported by vertical forces only – effectively a wheel-like translation, and a condition closely approximated by walking tortoises. If this is a potential strategy for zero mechanical work cost among quadrupeds, how might the structure, posture and diversity of both sprawled and parasagittal legs be interpreted? In order to approach this question, various linkages described during the industrial revolution are considered. Watt's linkage provides an analogue for sprawled vertebrates that use diagonal limb support, and shows how vertical-axis joints could enable approximately straight-line horizontal translation while demanding minimal power. An additional vertical-axis joint per leg results in the pull-out screen support as an analogue for tortoise limbs. This allows walking without any tipping or toppling, and has the potential to translate the body with zero work. The Peaucellier linkage demonstrates that parasagittal limbs with lateral-axis joints could also achieve the zero-work strategy. Suitably tuned four-bar linkages indicate this is feasibly approximated for flexed, biologically realistic limbs.

6-5 UYANIK, I; SEFATI, S; STAMPER, S A; CHO, K; ANKARALI, M M; FORTUNE, E S*; COWAN, N J; Hacettepe University, Ankara, Turkey, Johns Hopkins University, Baltimore, MD, Middle East Technical University, Ankara, Turkey, New Jersey Institute of Technology, Newark, New Jersey, Johns Hopkins University,Baltimore, MD; *ncowan@jhu.edu*
Variability in Locomotor Dynamics Reveals the Critical Role of Feedback in Task Control
Animals vary considerably in size, shape, and physiological features across individuals, but yet achieve behavioral performances that are virtually indistinguishable between conspecifics. We examined how animals compensate for morphophysiological variation by measuring the system dynamics of individual knifefish (*Eigenmannia virescens*) in a refuge tracking task. Kinematic measurements of *Eigenmannia*were used to generate individualized estimates of each fish's locomotor plant and controller revealing substantial variability between fish. To test the impact of this variability on behavioral performance, these models were used to perform simulated `brain transplants'---computationally swapping controllers and plants between individuals. We found that simulated closed-loop performance was robust to mismatch between plant and controller. This suggests that animals rely on feedback rather than precisely tuned neural controllers to compensate for morphophysiological variability.

111-6 VAN WASSENBERGH, S.*; BöHMER, C.; ABOURACHID, A.; Universiteit Antwerpen, Belgium, Muséum National D'Histoire Naturelle, France; *sam.vanwassenbergh@uantwerpen.be*

Analysis of the Shock Absorption Paradox in Woodpeckers

The beak and beak-braincase interface of woodpeckers are hypothesised to serve as a shock absorber to minimise the harmful deceleration of the woodpecker's brain upon impact when pecking trees. This idea has become the common believe of how these birds protect their brain against injury, and seems supported by the presence of a relatively large zone of spongy bone at the frontal region of the braincase. However, since any absorption or dissipation of the head's kinetic energy upon impact implies lower peak forces exerted by the tip of the beak on the tree, evolving any type of shock absorber will probably impair the bird's hammering performance. To study this 'woodpecker shock absorption paradox', we first analysed the kinematics of the upper beak and braincase (eye centre position) based on high-speed videos (up to 4000 frames per second) of two black woodpecker individuals (*Dryocopus martius*) during pecking, and found that decelerations virtually did not differ between the beak and the braincase during impact, indicating a very stiff beak-braincase interface. Secondly, forward dynamic modelling of wood penetration events by a head with variable degrees of shock attenuation confirms the adaptive advantage of such stiff cranial systems without shock absorption. Finally, numerical modelling predicted that intra-cranial pressure in *D. martius* safely remained below half of those corresponding to the approximate threshold of concussions in primates. Together, these results show that the multi-component cranial skeleton of the black woodpecker is used as a stiff hammer during pecking to optimise pecking performance, and not as a shock absorbing system to protect the brain.

52-2 VANDENBROOKS, JM*; VIMMERSTEDT, J; HUFFAKER, M; ANGILLETTA, JR., M; Midwestern University, Arizona State University; *jvandenbrooks@midwestern.edu*

Oxygen limits the thermal tolerance in embryos of terrestrial endothermic and ectothermic animals

Oxygen availability and temperature are two of the most important environmental factors affecting all of animal life. However, the two are not independent of each other and may exert similar selective pressures on animals. Life stages that have poorly developed circulatory systems or are incapable of oxygen regulation may be more susceptible to high temperatures at lower oxygen levels. Through a series of experiments on lizards, birds, and insects, we have begun to examine the interactive effect of oxygen and temperature on terrestrial animals exposed to hypoxia, high temperatures, and a combination of both during various life stages and levels of activity. While the results of these experiments have been mixed in their support for the concept of an effect of oxygen during periods of thermal stress, one pattern has emerged – the thermal tolerance of embryonic stages are particularly susceptible to oxygen variation. This pattern holds true for both ectotherms and endotherms. In embryonic lizards, hypoxia strongly reduced thermal tolerance, while hyperoxia mildly increased thermal tolerance. By contrast, quail embryos showed a marked decrease in thermal tolerance in hypoxia and a marked increase in thermal tolerance under hyperoxia indicating they are oxygen limited even under normal environmental conditions. However, while the embryos were significantly impacted by oxygen, the thermal tolerance of adult lizards and insects were unaffected by oxygen variation. Based on these experiments, the effect of oxygen on thermal tolerance varies depending on the life stage. More experiments under ecologically relevant conditions and behaviorally relevant activities need to be carried out to further test these hypotheses.

109-8 VANDEPAS, LE*; STEFANI, C; TRAYLOR-KNOWLES, N; BROWNE, WE; GOETZ, FW; LACY-HULBERT, A; National Oceanographic and Atmospheric Administration, Seattle, WA, Benaroya Research Institute, Seattle, Wa, Rosenstiel School of Marine and Atmospheric Sciences, University of Miami, Miami, FL, Dept. of Biology, University of Miami, Coral Gables, FL, University of Washington, Dept. of Immunology and Benaroya Research Institute, Seattle, Wa; *vandepaslauren@gmail.com*

Tick, Tick, Boom: Exploring diverse immune cell behaviors in ctenophores and oysters

Innate immunity is an ancient defense mechanism that operates in multicellular organisms to detect and eliminate pathogens and distinguish self from non-self. Animal immune cells deploy diverse behaviors during pathogen detection and elimination, including phagocytosis, secretion of inflammatory cytokines, and expulsion of nuclear material - the casting of extracellular DNA "traps" (e.g. ETosis). While cells capable of mammalian neutrophil-like ETosis behavior were recently described in several bilaterian invertebrate taxa, the cellular immune system of the non-bilaterian clade Ctenophora remains almost completely undescribed. We have developed and deployed microscopy and biochemical approaches to explore and compare immune cell behaviors in model ctenophore (*Mnemiopsis leidyi*) stellate cells and oyster (*Crassostrea gigas*) hemocytes. Our findings suggest a variety of cell types may be competent for a range of anti-microbial responses, including ETosis. We also find that some immune cell type behaviors may be activated by non-canonical signaling pathways. This data provides an opportunity to explore both conserved and novel aspects of pathogen defense mechanisms associated with the evolution of the animal innate immunity.

1-6 VARGAS, M*; MARTINEZ ACOSTA, VG; Univ. of the Incarnate Word; Marine Biological Laboratory; *mavarga9@student.uiwtx.edu*

Regeneration of Negative Phototactic Response in Lumbriculus variegatus

Lumbriculus variegatus, an aquatic annelid, is capable of regeneration from a few body segments (Martinez and Zoran, 2009). In this study, we investigate photoreception during regeneration. Photoreceptors are found within the posterior-most segments of an adult worm, as suggested by Drewes and Fourtner (1989). A simple phototactic assay demonstrates a suite of behavioral responses when regenerating worm fragments are exposed to white light. Anterior (Ant) and posterior (Post) worm fragments demonstrate significant differences in the amount of time to negatively phototact [Control (C) vs Ant p= 0.42, df=5: C vs Post p=0.047, df=5]. Worms were also tested using an environmental chamber that provides a native habitat filled with sediment layers. To better describe location of photosensitive cells in posterior segments, Anti-Futsch (22c10; Developmental Hybridoma Bank) and Anti-G- Subunit q/11/14 (Santa Cruz Biotechnology) antibodies, previously described as markers for photoreceptors in other worm species, were used. 22c10 immunoreactivity was localized to the cytoplasm within cells found along the ventral epithelial surface of the worm. These 22c10 positive cells are found adjacent to serotonergic axonal connections that extend toward the ventral nerve cord. G-alpha protein was more broadly expressed within small epithelial cells extending into the cuticle as well as within neuronal cell bodies extending from the ventral nerve cord. Taken together these data represent one of the most extensive studies of photoreception in *Lumbriculus*.

53-1 VARGAS, R*; VALENTINI, A; GARCIA, M; STEFFENSON, M; St. Edward's University; *rvargas6@stedwards.edu*
The Immunological Response of Leg Autotomy in Tigrosa helluo Involving Hemocyte Protein Analysis
Autotomy is a survival mechanism utilized by various organism, in which an individual voluntarily loses a body part in response to an external stressor, often in the form of a predator attack. While this capability is a benefit towards immediate survival, there are notable impediments towards the overall survival of an autotomized individual. Behavioral and physiological alterations are commonly present following the autotomy event. The molecular components aiding in the recuperation of an organism after the loss of a leg have been of particular interest as they are indicative of the organism's overall immunological activity. In invertebrates, the hemocytes incorporated within hemolymph are important factors in cellular immunity. Within responses to leg autotomy, hemocyte interactions with foreign matter entering through an open wound can be assessed through the various proteins involved with the hemocyte activity. By analyzing the proteins present in the hemolymph of the wolf spider *Tigrosa helluo* after autotomy, we were able to identify the overall presence and function of the proteins associated with this stress response. Protein concentration and prophenoloxidase activity, a precursor for the organisms encapsulation response, was measured in both the controlled and autotomized female *Tigrosa helluo* and the control sample of the males. While there was no significant differences between either of the parameters across any of the sample groups, the observed patterns of this preliminary data suggests a possible difference between protein activity in females and males, and a difference in the prophenoloxidase activity in autotomized individuals compared to non-autotomized individuals.

48-8 VARNEY, RM*; SPEISER, DI; KOCOT, KM; Univ. of Alabama, Univ. of South Carolina; *rvarney@crimson.ua.edu*
The genome of the chiton Acanthopleura granulata: perspectives on biomineralization from polyplacophorans
The wide diversity of structures produced through biomineralization by molluscs has long been of interest to materials science. Despite technological advances, materials produced by molluscs at ambient temperature and pressure are often superior to manufactured materials in their combinations of desirable features (e.g. strength and flexibility). Chitons (Mollusca; Polyplacophora) are a promising system in which to study biomineralization because they produce a wide range of calcified structures including shell plates and sclerites. They also coat the teeth of their tongue-like radula with a range of iron oxides including magnetite. Comparative genomics permits comparisons of genetic toolkits across molluscs. Here we present the first genome of a chiton, the first from any aculiferan mollusc. We employed a hybrid assembly strategy combining Illumina and Oxford Nanopore followed by optical mapping. We produced a 605.9 Mbp assembly in 87 scaffolds with an N50 of 23.9 Mbp and a BUSCO score of 96.2%. We identified many genes hypothesized to be part of the biomineralization toolkit of conchiferan molluscs. To better understand how chitons produce iron structures, we analyzed known iron-associated proteins and located chiton-specific iron-binding regulatory sites in the untranslated regions of certain genes. We will combine further screening for iron-regulatory domains with sequencing of transcriptomes to determine gene expression patterns underlying the biomineralization of iron oxides such as magnetite. By comparing the genetic toolkits of conchiferans and aculiferans, we will be able to reconstruct the ancestral suite of biomineralization genes in molluscs. Further, by sequencing the first genome of a chiton, we are now better-positioned to study both the evolution and mechanisms of the natural production of iron structures in chitons.

136-2 VAZ, D/F*; HILTON, E/J; Virginia Institute of Marine Science, College of William & Mary; *dbistonvaz@vims.edu*
When Five Means Four (and Something Else): Ontogeny of the Pectoral Fin of the Plainfin Midshipmen, Porichthys notatus (Batrachoididae: Batrachoidiformes), with implications to evolution of Batrachoidiformes
Batrachoidiformes is a monophyletic group of mostly benthic, ambush-predatory fishes, and characteristic for having large pectoral fins. This order is unique for having the skeleton of the pectoral fin with five radial basals, in contrast to four found in other fishes. The homology of each radial basal, however, is uncertain. A hypothesis for the higher number of radial basals would be an additional segmentation of the embryonic pectoral radial plate during early life development. To investigate such question, a series of the early life stages of Plainfin Midshipmen, Porichthys notatus (5 to 28 mm TL), was collected during the summers of 2017 and 2018, and skeletal ontogeny was investigated by clearing-and-staining. Results obtained from early stages of P. notatus were used as a proxy to explain the variation in the order. The early stages of development (6-7 mm TL) of the petoral fin of P. notatus have two cartilaginous structures: a pectoral radial plate and the propterygium. Later development shows that the segmentation of the pectoral radial plate forms the four ventral radial basals. At 7-8 mm TL, the propterygium grows in its longitudinal axis and fuses with a group of cells that migrate from the pectoral radial plate, forming the dorsalmost "radial basal". These findings have implications to the systematics of Batrachoidiformes. In genera Triathalassothia, Batrichthys, Riekertia, Halobatrachus, and Perulibatrachus, the dorsalmost basal radial (i.e., compound propterygium) remains cartilaginous, similar to found in other fishes (i.e., plesiomorphic state). All other species of Batrachoidiformes have an ossified compound propterygium and this shared feature might be an evidence of shared ancestry.

87-1 VAZQUEZ, S; PHAN, A; JOSEPH, M; PACE, CM*; Le Moyne College; *pacecm@lemoyne.edu*
The aerial righting ability of the brown marmorated stink bug, Halyomorpha halys.
How an animal recovers from perturbations in stability, such as falling, can have consequences for how it survives and thrives. Falling winged insects right themselves mid-air via asymmetric flapping and flightless insects have been shown to use leg positioning to achieve aerial righting success. However, how different morphologies impact insect aerial righting ability is unknown. Unlike previously studied insects, *Halyomorpha halys* is characterized by a broad flat shield-like body. In addition, *H. halys*'s locomotor abilities become seasonally impaired in the winter during diapause, potentially affecting flight. To assess the contribution of different morphological structures on *H. halys*'s aerial righting ability, landing success and timing of locomotor events were recorded from the following morphological categories: alive; alive with the wings glued shut; dead; and dead with the legs removed. *H. halys* was filmed at 1000Hz falling after being dropped from a ventral side-up starting position. Landing success of dead *H. halys* (both intact and with legs removed) was low (~30%). While living *H. halys* (both intact and with wings glued shut) had a higher landing success (~75%). This suggests that morphology alone isn't sufficient for successful landing. Living *H. halys* spread their legs wide upon initiation of falling and intact *H. halys* opened their wings shortly after while still upside down in the air. It is unclear how (or if) leg positioning changes when wings are unable to open and it is possible that *H. halys* switches between different aerial righting strategies depending on the circumstances.

119-1 VAZQUEZ-MEDINA, JP*; ALLEN, KN; TORRES-VELARDE, JM; LAM, EK; University of California, Berkeley; *jpv-m@berkeley.edu*

Primary tissue culture provides a system for functional genome-to-phenome investigations in marine mammals

Marine mammals exhibit dramatic physiological adaptations and offer unparalleled insights into mechanisms that drive convergent evolution on a short time-scale. Some of those adaptations (i.e. extreme tolerance to hypoxia, prolonged food deprivation) challenge established principles of matching metabolic supply and demand. Non-targeted omics studies have begun to uncover the genetic basis of such adaptations, but tools for testing their functional significance are currently lacking. A powerful approach for understanding the molecular etiology of physiological adaptation is cellular modeling, which is essential for accelerating genome-to-phenome research in organisms in which transgenesis is impossible. Gene perturbation in primary cells can directly evaluate whether positive selection or gene loss confers functional advantages such as hypoxia or stress tolerance. Hence, we have established ex vivo systems (skeletal muscle myotubes, flow-adapted endothelial cells) to conduct functional studies that can provide the missing link between genome- and organism-level understanding of physiological adaptation in marine mammals. Using these systems, we are starting to uncover the adaptive responses that drive stress tolerance in elephant seal muscles, which can switch metabolic pathways to support ATP production during chronic exposure to glucocorticoids. We are also dissecting the molecular drivers of hypoxia and oxidative stress tolerance in seal endothelial cells, which face constant fluctuations in oxygen tension derived from the diving response. Finally, we are developing adipocyte cultures from mesenchymal stem cells and muscle cells from reprogrammed skin cells to study the molecular drivers of metabolic adaptation in less accessible species.

43-6 VELOTTA, JP*; ROBERTSON, CE; SCHWEIZER, RM; MCCLELLAND, GB; CHEVIRON, ZA; University of Montana, McMaster University; *jonathan.velotta@gmail.com*

A developmental delay in thermogenesis is associated with adaptive shifts in gene expression in high-altitude deer mice

Aerobic performance is strongly tied to fitness as it often determines an animal's ability to find food, escape predators, or survive extreme conditions. At high-altitude, where severe reductions in O_2 availability and cold temperatures prevail, maximum metabolic heat production (thermogenesis) is a performance trait that has evolved under natural selection. Understanding how thermogenesis evolves to permit survival at high-altitude will yield insight into the links between integrated physiology, whole-organism performance, and fitness. Previous work in deer mice (*Peromyscus maniculatus*) suggests that low O_2 availability at high-altitude forces a trade-off, whereby developing deer mouse pups delay the onset of thermogenesis in order to preserve limited energetic resources. In order to determine the mechanistic causes of this delay, we analyzed the transcriptomes of thermogenic organs, brown adipose tissue (BAT) and skeletal muscle, across the first 27 days of post-natal development in deer mice native to low- and high-altitude. We show that developmental delays in thermogenesis are correlated with shifts in the expression of gene regulatory networks that function in nervous system control, fuel supply, and vascularization of BAT, and aerobic metabolism and mitochondrial function in skeletal muscle. These results suggest that the delay in thermogenesis is attributable to a delay in the activation and aerobic capacity of thermo-effector organs. We provide evidence that many of the regulatory changes are adaptive. Our results suggest that a delay in the development of thermo-generation is adaptive at high-altitude, and may represent an alternative resource allocation strategy to balance competing energetic trade-offs.

76-3 VEGA, CM*; ASHLEY-ROSS, MA; Wake Forest University; *vegacm11@wfu.edu*

Turtling the salamader: the role of lateral undulation in sprawling limb kinematics

Lateral undulation and trunk flexibility which offer performance benefits to maneuverability and stability are important characteristics of sprawling postured tetrapod locomotion except for turtles. Despite their bony carapace preventing lateral undulations, turtles have been able to improve their locomotor performance by increasing stride length via greater limb protraction. Would a generalized sprawling tetrapod respond with the same kinematic changes if lateral undulations were limited? The goal of this study was to determine the role of the lateral movement of the vertebrae in tiger salamanders (*Ambystoma tigrinum*) by reducing the role of vertebral flexibility. This was done by artificially limiting trunk flexibility by attaching a 2-piece "shell" around the body between the pectoral and pelvic girdles. Adult tiger salamanders (n =3, SVL = 9 cm-14.5 cm) walked on a 1 m trackway under three different conditions: no shell, flexible shell (tygon tubing), and rigid shell (PVC tubing). Trials were filmed in a single, dorsal view using a Kodak Playsport camera (30 fps). Kinematic markers on the fore and hindlimbs were digitized using DLTdataviewer5. Protraction and retraction angle calculations and statistical analyses were performed in R. We thus predict that increased range of limb movement may be a compensatory mechanism available to a wide range of tetrapods challenged with reduced lateral undulation.

79-4 VERNASCO, BJ*; DAKIN, R; SISSON, Z; HAUSSMANN, MF; RYDER, TB; MOORE, IT; Washington State University, Carleton University, Bucknell University, Bucknell University, Smithsonian Migratory Bird Center, Virginia Tech; *ben.vernasco@wsu.edu*

Using Telomeres to Assess Patterns of Biological Aging in a Cooperative Lek-breeding Passerine, the Wire-Tailed Manakin (Pipra filicauda)

Telomere lengths are reflective of an individual's biological age as telomeres shorten in response to both environmental and physiological perturbations and shorter telomeres are associated with higher mortality risks. Therefore, telomere length measurements can be used to understand what factors influence aging rates as well as how reproductive behaviors vary as an individual's mortality risk increases and future reproductive potential declines. Here, we measured the telomere lengths and reproductive behaviors of known-age, male wire-tailed manakins (*Pipra filicauda*) to understand how telomeres relate to a male's chronological age, social status, and reproductive investment. Wire-tailed manakins are a lekking passerine and males form cooperative display coalitions wherein multiple males perform coordinated courtship displays for females, but only one male within the coalition reproduces. Male wire-tailed manakins must ascend a social hierarchy as floater males and only gain reproductive opportunities upon becoming a territory-holder. More cooperative floater males are quicker to become a territory-holder and more cooperative territory-holder sire more offspring. Our results show that only among territory-holding males do telomere length decline with age. Additionally, independent of a male's age and social status, those with shorter telomeres interacted with coalition partners more frequently, maintained more exclusive positions within their social network, and tended to have more coalition partners. Overall, we identify status-specific patterns of aging and our results suggest males increase their reproductive investment as their future reproductive potential declines.

117-7 VETTER, BJ*; SISNEROS, JA; University of Washington; *bjvetter@uw.edu*

The swim bladder enhances sound pressure sensitivity and bandwidth of the lagena in female plainfin midshipman (Porichthys notatus)

The plainfin midshipman fish (Porichthys notatus) is an established neuroethological model for investigating mechanisms of acoustic communication because the reproductive success of this species is dependent on the production and reception of social acoustic signals. Midshipman possess three otolithic end organs capable of sound detection. The largest of these is the saccule and the sensitivity of this hearing end organ is well established, but the sensitivity and function of the putative auditory lagena is less understood. Previously, we showed that the midshipman lagena had a similar low-frequency sensitivity to that of the saccule but the lagenar thresholds were much higher. Furthermore, work from our lab demonstrated that midshipman possess sexually dimorphic swim bladders that effectively enhance sound pressure detection. The swim bladders of females have rostral horn-like extensions that project close to the inner ear end organs, especially the lagena, while nesting males lack such extensions. The aim of this study was to determine whether these swim bladder extensions enhance auditory lagenar sensitivity to sound pressure and higher frequencies. We characterized the lagenar sensitivity of reproductive females with intact (control) and removed swim bladders. Our results show that control females with intact swim bladders displayed auditory evoked lagenar potentials up to 1005 Hz while females with removed swim bladders displayed evoked potentials only up to 505 Hz. Furthermore, the control females had the lowest thresholds (highest sound pressure sensitivity), with average thresholds at the characteristic frequency (85 Hz) that were 6 dB lower than those without swim bladders. These findings suggest that the midshipman lagena is sensitive to sound pressure indirectly and maybe important for the detection of social acoustic signals.

35-3 VITEK, NS*; MCDANIEL, SF; BLOCH, JI; Stony Brook University, NY, University of Florida, Gainesville, FL , Florida Museum of Natural History, Gainesville FL; *natasha.vitek@stonybrook.edu*

Is variation in molar tooth crown morphology of the Grasshopper Mouse (Onychomys leucogaster) a reflection of selection or drift?

A longstanding question in evolutionary biology is to understand the role of local adaptation, as opposed to neutral processes, in shaping morphological variation among populations. Differentiating between these alternatives for fossil bones and teeth is critical for interpreting the drivers of historical change. However, this work is particularly challenging because molecular indicators of selection and drift are lacking in fossils. Here we used the molars of the extant, insectivorous rodent *Onychomys leucogaster* as a test case to develop expectations for the fossil record. The similarity across environments of the insects comprising the diet of *O. leucogaster*, at least with respect to their mechanical properties, suggest that selection on molars, primarily through diet, may be homogeneous across the distribution of the species. We used geometric morphometrics to measure morphology, ddRAD sequencing to estimate population structure, and measures of climate, primary productivity, and phenology to measure environment. We evaluated support for the two hypotheses by comparing morphology, population structure, and environment while accounting for geographic distance via P_{ST}-F_{ST}-comparisons using multiple matrix regression with randomization. Depending on whether we quantified morphology in terms of size, shape, or size and shape together, we found variably significant relationships between morphology and population structure, but never with environment or geographic distance. In sum, these results indicate that we cannot eliminate drift as the mechanism driving morphological divergence in tooth shape and size.

9-7 WAGNER, JM*; PARKER, J; California Institute of Technology, Pasadena; *jwagner2@caltech.edu*

Chemical Cues Underly an Interspecies Symbiosis by Triggering a Modular Social-Behavioral Program

Interspecies social behaviors have traditionally been challenging to study because they are difficult to reconstitute in lab. Here, we demonstrate a stereotyped, robust interspecies grooming program for study of social behavior. *Sceptobius lativentris* is a host specific guest rove beetle which infiltrates colonies of the velvety tree ant (*Liometopum occidentale*). The beetle is the quintessential social parasite: it dies rapidly when isolated from ants, has lost its wings and disperses on ant trails, and grooms host ants to steal their nestmate recognition pheromones (CHCs), which it uses to disguise inside colonies. Using infrared illuminated behavioral arenas, we have reconstituted the beetles' stereotyped grooming program in lab which we have annotated with deep learning tools. Though *S. lativentris* exhibits strict host specificity in nature, it promiscuously grooms divergent species of ants. It does not, however, groom a hemipteran which peripherally associates with *L. occidentale*. We hypothesize that a core set of cuticular pheromones conserved in ants provide the odor cue triggering *S. lativentris* social behavior. To test this, we employed a robotized ant-beetle interaction arena which allows application of ant chemicals to a moving dummy object. This arena gives a controlled set up to demonstrate the necessary and sufficient cues for *S. lativentris* grooming. In addition to establishing the behavioral tractability of *S. lativentris* as a model system of social symbiosis, we have also worked to establish molecular tools for the beetle. We performed RNA sequencing of the beetle and olfactory structures (legs, antennae), assembled its transcriptome, and annotated odorant and gustatory receptors. Together, these behavioral and molecular tools establish an exciting new system to investigate social symbiosis.

73-7 WAINWRIGHT, DK*; SUMMERS, DA; Yale University, New Haven CT, Harvard University, Cambridge MA; *dylan.wainwright@gmail.com*

Crushing prey in the open ocean: the pharyngeal jaws of lanternfishes

Lanternfishes are a diverse family of fishes with 246 described species that live in open ocean waters worldwide. These fishes are estimated to account for over 60% of deep-sea fish biomass and are crucial food sources for many larger fishes, cetaceans, and squids. Many lanterfishes live deeper in the water column during the day, but migrate closer to the surface at night to consume zooplankton. Despite the clear ecological and evolutionary importance of lanternfishes for open ocean environments, we generally know little about this group due to the difficulties of observing them alive. In order to develop our ecomorphological knowledge of lanternfishes, we have used μCT to study their cranial morphology, with a special focus on pharyngeal jaws. Pharyngeal jaws are common to all teleosts and are a second set of jaws formed by modifying the posterior-most set of gill arches into tooth-bearing bones that can help process and transport food. We demonstrate that one clade of lanternfishes (Gonichthys spp. and Centrobranchus spp.) have highly modified pharyngeal jaws, where the upper tooth plates have enlarged molariform teeth and appear to occlude in a lateral-medial fashion, as opposed to the normal arrangement where upper and lower tooth plates occlude in a dorso-ventral fashion. The modified upper pharyngeals are hypertrophied and crush prey between the left and right upper tooth plates using enlarged musculature and a novel muscle attachment. Unlike other lanternfishes, the clade of species with modified jaws specializes in consuming planktonic shelled gastropods. This discovery represents a unique and novel instance of durophagy by a small-bodied, open-ocean, and zooplanktivorous group of fishes.

S10-10 WALDROP, LD*; MOHAMMADI, S; RADER, JA; HE, Y; Chapman University, UNC Chapel Hill, University of North Texas; *waldrop@chapman.edu*

Using uncertainty quantification to infer physical constraints on the evolution of fluid-structure functional systems

Understanding evolution, in part, requires understanding how variation will change the functional performance of biological structures. Variation provides the raw material on which natural selection acts to shape these structures, but the performance consequences of variation are difficult to predict in complex, non-linear functional systems. Computational models have long been used to better understand the biomechanics of biological structures, but their usefulness has been historically limited in informing studies of evolution. This work strives to integrate the detailed, computational models with studies of evolution and morphological diversity through unique quantitative analysis tools. We apply uncertainty quantification to simple computational models of three functional systems involving fluid-structure interactions: odor-capture by crustacean antennules, blood-pumping by the tubular hearts of tunicates, and gliding performance in birds. We use generalized polynomial chaos expansions in conjunction with Sobol indices to assess and describe the role of variation in the performance of each system across a wide morphological and kinematic space. From these techniques, we infer the strength of physical constraints on the evolution of biological structures in each system.

S10-0 WALDROP, LD*; RADER, JA; Chapman University, UNC Chapel Hill; *waldrop@chapman.edu*

Introduction to Melding Modeling and Morphology

Biomechanics seeks to understand the form and function of organisms. Researchers have largely taken two tacks toward this goal: 1) observing and modeling representative organisms to infer form based on function, or 2) quantifying trait diversification and evolutionary constraint to infer function based on form. This has led to the development of sophisticated tools including, but not limited to mathematical and computational modeling on first tack, and geometric morphometrics, classic biomechanics manipulation experiments, and phylogenetics on the other. These are powerful approaches, and they have much to offer each other toward understanding the evolution and biodiversity of form and function, yet there has been little work to date on combining computational modeling and morphometrics. A few works have started to bridge this divide, but these methods are under-developed and not widely used. Recent advancements in computational power that previously limited attempts to both model function and to handle and analyze large data sets make this an ideal moment to spur development of collaborative efforts, and as such, the purpose of this symposium is to examine the idea of studying the evolution of functional structures using mixed methods of classic biomechanics, together with computational and mathematical modeling, all in a phylogenetic framework. The symposium brings together speakers with backgrounds in both approaches with the hope of promoting ideas by speakers who have worked to develop methods to bring both sides together.

64-2 WALKER, S M*; CHRISTEN, P; TAYLOR, G K; University of Leeds, University of Applied Sciences and Arts Northwestern Switzerland , University of Oxford; *s.m.walker@leeds.ac.uk*

Haltere kinematic and dynamics measured using time-resolved microtomography

Halteres are the dumbbell-shaped, reduced hindwings found in Diptera (true flies) and are a defining feature of the order. During flight, the halteres beat in antiphase with the wings and function as gyroscopic sensors of Coriolis force produced during whole body manoeuvres. This rapid sensory mechanism is one of the reasons why flies are amongst the most agile and manoeuvrable of all flying insects. However, in order to detect the tiny Coriolis forces, halteres must be exquisitely tuned so that the signal is not masked by the much larger inertial forces due their own acceleration. This is believed to be achieved by beating in a perfect plane, which allows the orthogonal component of the Coriolis forces to be detected in isolation from the primary forces. However, this has not been confirmed experimentally. Here, we use time-resolved microtomography to visualise the halteres in tethered blowflies, *Calliphora vicina*, during induced roll manoeuvres. We used the measured 3D haltere kinematics to calculate the corresponding dynamics. Surprisingly, we found large primary forces acting in the same plane as the Coriolis forces. These were caused by significant out-of-plane motions at the haltere base, and may be an artefact of tethering. Furthermore, this base motion produces a force that matches the Coriolis forces that would be produced by a constant pitching motion. Flies will therefore be sensing a fictitious force during tethered flight that could result in changes to their behaviour and requires careful consideration when designing such experiments.

68-3 WALL, CB*; RITSON-WILLIAMS, R; POPP, BN; GATES, RD; University of Hawai'i at Mānoa, California Academy of Sciences, Hawai'i Institute of Marine Biology; *cbwall@hawaii.edu*

Spatial variation in biochemical and isotopic composition of corals during bleaching and recovery

Ocean warming and the increased prevalence of coral bleaching events threaten coral reefs. However, the biology of corals during and following bleaching events under field conditions is poorly understood. We examined bleaching and post-bleaching recovery in *Montipora capitata* and *Porites compressa* corals that either bleached or did not bleach during a 2014 bleaching event at three reef locations in Kāneʻohe Bay, Oʻahu, Hawaiʻi. We measured changes in chlorophylls, tissue biomass, and nutritional plasticity using stable isotopes (^{13}C, ^{15}N). Coral traits showed significant variation among periods, sites, bleaching conditions and their interactions. Bleached colonies of both species had lower chlorophyll and total biomass, and while *M. capitata* chlorophyll and biomass recovered three months later, *P. compressa* chlorophyll recovery was location-dependent and total biomass of previously bleached colonies remained low. Biomass energy reserves were not affected by bleaching, instead *M. capitata* proteins and *P. compressa* biomass energy and lipids declined over time and *P. compressa* lipids were site-specific during bleaching recovery. Stable isotope analyses did not indicate increased heterotrophic nutrition in bleached colonies of either species, during or after thermal stress. Instead, mass balance calculations revealed variations in ^{13}C values reflect biomass compositional change (i.e., protein:lipid:carbohydrate ratios). These results highlight the dynamic responses of corals to natural bleaching and recovery and identify the need to consider the influence of biomass composition in the interpretation of isotopic values in corals.

96-7 WAN, KY; University of Exeter, UK; *k.y.wan2@exeter.ac.uk*
Gait Rhythmogenesis and Spatiotemporal Ordering in Self-propelling Unicellular Microorganisms
Interlimb coordination is a highly dynamic phenomenon which enabled the first vertebrates to negotiate terrestrial habitats during the evolutionary transition from sea to land. Surprisingly, attainment of complex limb coordination is by no means exclusive to organisms that possess a nervous system. Instead, single-celled microeukaryotes, which may be mere microns in size, can also enact complex movement gaits for swimming using multiple, fast-moving locomotor appendages called cilia and flagella. These appendages are structurally and functionally similar to epithelial cilia, which in mammalian systems are responsible for directional flow generation and transport. Here, I demonstrate novel features of spatiotemporal flagellar coordination in unicellular algae. I show that the algal flagellar apparatus - comprising basal bodies and interflagellar fibres - actively couples groups of flagella to achieve dynamic locomotor patterning. Resolving gait dynamics at the single-flagellum level in both free-swimming and micropipette-fixed individuals, I will demonstrate spontaneous transitions in behaviour including gait-intermittency, reversible rhythmogenesis, and gait-mechanosensitivity. In particular, during forward propulsion quadriflagellate algae can actuate four flagella to assume trotting or gallop gaits, but oscillations can be activated/inactivated selectively in subsets of the flagella. These findings suggest that a network of intracellularly-coupled algal flagella can function as a central pattern generator, which allows for distinguishable control and ordering of individual oscillators in the network and thus complex symmetry-breaking dynamics. Such symmetry-breaking processes provide a means for cell reorientation (such as towards light for photosynthesis) and responsive navigation in complex environments.

120-4 WANG, J; QI, Z; HAN, P; DONG, H; WAINWRIGHT, DK; LAUDER, GV; ZHU, J*; BART-SMITH, H; University of Virginia, Harvard University; *justinwang2011@gmail.com*
Tuna robotics: Computational FSI optimization of a tuna tail-informed propulsor with high efficiency
In this work, a combined experimental and computational approach is used to find the optimal structural design for a tuna-based robotic model (tunabot) that can achieve high tail beat frequency (up to 15Hz). The numerical modeling approach employs a flow-structure-interaction (FSI) immersed boundary solver for low-Reynolds number viscous flows. The experimental approach uses a stereo-videographic technique to obtain the three-dimensional, time-dependent caudal fin deformation and kinematics of a yellowfin tuna in steady swimming. Informed by the biological data, an inverse structure design method together with a gradient-based optimization method are then used to find the optimal structure design of the propulsor for the tunabot to achieve efficient swimming. The primary objectives of the computational effort are to quantify the swimming performance of the tunabot with different bending stiffness in tail design as well as to investigate the role of chord-wise flexibility and spanwise-wise flexibility in high-performance robot model design. The results of this work will also help us to examine the key hydrodynamic features shared by the robot swimming and fish swimming and lay the foundation to explore a fish-like performance space for bio-inspired autonomous underwater vehicles.

76-1 WANG, Y*; OTHAYOTH, R; LI, C; Johns Hopkins University; *ywang460@jhu.edu*
Cockroaches bend head and use legs differentially to traverse grass-like beam obstacles
Cockroaches are excellent at traversing dense obstacles in complex terrain. For example, to traverse grass-like beam obstacles, the discoid cockroach often transitions from a pitch mode, in which its body pitches up against the beams, to a roll mode, in which its body rolls to align with the gaps between beams. A recent study in our group found that passive body vibration from oscillatory leg propulsion helped discoid cockroaches and robots traverse grass-like beam obstacles, because the kinetic energy fluctuation helps the body overcome a potential energy barrier to transition from the pitch to the roll mode. Here, we further study the neuromechanics of traversal by measuring active adjustments of head and legs (N = 8 individuals, n = 64 trials). We attached BEEtags to the animal body and head and small markers to the abdomen and legs and used automatic marker and DeepLabCut tracking to obtain ~200,000 digitized points to reconstruct detailed 3-D kinematics. When the animal pitched up against the beams (body pitch angle = 33° ± 15°), its head flexed repeatedly (standard deviation of bending angle = 8.8°). Then, the animal used its two hind legs differentially, extending one while flexing the other (difference in toe distance from body coronal plane between left and right legs = 10 ± 3 mm). These adjustments helped the animal transition to the roll mode into the gap, after which the hind legs pushed to propel forward while the abdomen flexed (standard deviation of flexion angle = 8.5°) to reduce terrain resistance (P < 0.05, ANOVA). A potential energy landscape model with a bendable head suggested that head bending lowered the potential energy barrier to transition from the pitch to the roll mode. Our study showed that active adjustments complement passive mechanics to help animals traverse complex terrain.

S8-5 WARD, AB*; REDMANN, E; ALQAHTANI, A; SHEIKH, A; MEHTA, RS; Adelphi Univ, UC Santa Cruz; *award@adelphi.edu*
East Coast Travel Is An Uphill Battle: Terrestrial locomotion in American Eels
Extreme body elongation is often linked with the ability to move between aquatic and terrestrial habitats. Fish are known to move onto land to escape poor water conditions, for better breeding sites, or other high quality resources. One highly elongate species known to traverse terrestrial environments is the American eel (*Anguilla rostrata*). American eels have a unique life cycle during which eggs are laid in the Sargasso Sea and leptocephalus larvae are transported along the coast. Glass eels then move into freshwater systems and mature into yellow eels which may spend decades in freshwater prior to becoming sexually mature (silver eels) and returning to the Sargasso Sea to reproduce. Along the east coast of the United States, many of the rivers from where American eels may migrate are blocked by dams. Despite this anthropogenic barrier, eels are found upstream of dams. Previous work has shown that glass eels can climb the vertical sides of a dam, but this behavior has not been described in older eels. In this study, we expand our understanding of eel terrestrial locomotion by examining eels moving along sand, loose pebbles, and fixed pebble substrate) and 4 inclines ranging from 0 to 15 degrees. Eels were resistant to climbing the higher inclines and often moved into a concertina-like locomotion in comparison to the undulatory locomotion they often used at lower angles. Distance ratio, a measure of the effectiveness of movement, was lower at higher inclines indicating more lateral movement of the body. These experiments reveal that steep inclines 15+ degrees impose additional effort on locomotion for this commercially important fish. By understanding these constraints, we can help develop management strategies to mitigate the increased energetics imposed by dams.

70-1 WARDILL, TJ*; FEORD, RC; SUMNER, ME; PUSDEKAR, S; KALRA, L; GONZALEZ-BELLIDO, PT; University of Minnesota, University of Cambridge; *twardill@umn.edu*
Binocular stereopsis in cuttlefish improves prey targeting.
To assess depth information, some animals utilize the disparity between left and right visual fields, in a process called stereopsis. This strategy is commonplace in vertebrates, having evolved multiple times independently. However, only one invertebrate species, the praying mantis, has been demonstrated to possess stereoscopic vision. Here, we set out to test for stereopsis in cuttlefish, a cephalopod mollusk. In addition to their notorious cognitive and camouflage abilities, cephalopods are visually driven hunters. The camera type eyes of cephalopods exhibit remarkable convergence to those of vertebrates, both in their anatomical features and vergence movements. However, neither squid or octopuses appear to employ stereopsis to resolve depth; squids use monocular retinal deformation and blur, and the limited overlap of visual fields from both eyes in octopuses makes the use of stereopsis unlikely. Cuttlefish, however, can produce significant binocular overlap through ocular vergence, though it remained unclear whether they employ stereopsis for their predatory attack. Here we show that cuttlefish (1) use stereovision to resolve the distance to prey, (2) use this information to shorten the time and distance covered prior to striking at a target, (3) likely process visual motion differently to vertebrates, as they can extract stereopsis cues from anti-correlated stimuli, and (4) can switch eye movements from independent to conjugated. These results show that stereopsis has evolved independently in another non-vertebrate group, but with camera-type eyes. Since the organization of the cephalopod brain is considerably dissimilar to that of vertebrates, this finding opens a door for investigating if cuttlefish have evolved alternate processing mechanisms for stereo perception.

131-5 WARGIN, AH*; COMBES, SA; University of California, Davis; *ahwargin@ucdavis.edu*
BEEhavior under pressure: Testing the effects of barometric pressure change on bumblebee foraging behavior
Bumblebees, some of world's most important pollinators, do not store large amounts of food within their hives, so they must respond rapidly to changing conditions in order to survive adverse weather events. Heavy rainstorms pose a particular challenge, as they can prevent foragers from collecting food, and may prove fatal for foragers caught outdoors. Heavy rain is typically preceded by a drop in barometric pressure, and a handful of studies have shown that other types of insects can detect and respond to these changes; however, no previous studies have explored whether changes in barometric pressure affect the behavior of bees. Here, we manipulated barometric pressure in a laboratory setting to investigate how pressure changes affect the foraging and nest activities of bumblebees (*Bombus impatiens*). We placed a hive of bumblebees inside an airtight chamber where they needed to exit the nest box to forage for nectar within the chamber. We pumped air through the chamber continuously, and controlled inflow and outflow rates using proportional valves to produce three different types of 6-hour barometric pressure regimes: constant pressure, rising pressure, or falling pressure. We subjected the hive and foraging chamber to a different pressure regime each day, and recorded foraging activity using motion-triggered image acquisition in the tunnel through which bees exited and entered the nest. Nest activity was recorded by capturing a 10-second video of the entire hive every 10 minutes. Each bee was outfitted with a BEEtag (QR code) on their thorax before trials began so that individual identity and orientation could be extracted from images. Our data show that changes in barometric pressure affect bumblebee activity in several ways, suggesting that bumblebees can not only detect pressure changes but respond behaviorally to prepare for imminent changes in the weather.

127-3 WATERS, JS; Providence College; *jwaters2@providence.edu*
Ants of Providence
Biodiversity surveys are critical tools for understanding fundamental patterns and shifts in the distribution of life across the planet. While the ant fauna (Hymenoptera: Formicidae) throughout most of New England has been extensively sampled, relatively few surveys have been conducted in Rhode Island. Working with undergraduate students and members of the community, we surveyed for ant species at two sites in Providence, Rhode Island, from 2015-2019. Manual collection and a 10-week repeated pitfall trap sampling method was used at Providence College and a rapid biological assessment (bioblitz) was conducted at Roger Williams Park. A total of 36 species were identified including the first observations of the introduced Asian needle ant (*Brachyponera chinensis* Emery, 1895) in New England. Twenty-six species identified were new county records and seven species were new state records, representing a substantial update to the list of known ants in Rhode Island, currently totaling 67 species from five subfamilies. These results fill an important gap in our knowledge of New England ant fauna, they are comparable with similarly scaled surveys conducted at parks and cities across the world, and they also question assumptions about the effects of urbanization on species diversity.

130-5 WATSON, CM; Midwestern State University; *charles.watson@msutexas.edu*
Comparative Ecology and Physiology of Anoles on Dominica
The Island of Dominica is currently home to two species of anole, the endemic Dominican Anole (*Anolis oculatus*), and the invasive Puerto Rican Crested Anole (*Anolis cristatellus*). While some populations of the native lizard seem to experience minimal deleterious effects of the invasive, others appear to be extirpated from areas where they are present. We measured ecological and physiological variables for these species to determine differences between the two anoles as well as differences among and within populations for each species. Here I discuss variation among different populations of *Anolis oculatus* and how those differences may influence their ability to compete and/or coexist with *Anolis cristatellus*. I also present evidence for local adaptation to temperature by *Anolis cristatellus*, which may allow them to eventually inhabit all but the most extreme environments on the island. While our knowledge of these species' biology remains incomplete, we are beginning to gain a better understanding of underlying factors affecting interspecific interactions, intraspecific variation, and the extent of their ranges on Dominica.

107-1 WEAVER, RJ*; GONZALEZ, B; SANTOS, SR; HAVIRD, JC; University of Texas, Austin, Hawaii Baptist Academy, Auburn University, Auburn; *ryan.weaver@utexas.edu*

How does a shrimp become red? From molecules to putative genes underlying variation in red carotenoid coloration of Halocaridna rubra

Variation in coloration within a species can result from selective pressures of the environment, genetic differences, or physiological constraints. The genetic basis for red carotenoid coloration in birds and turtles was recently identified as *CYP2J19*. This gene encodes a cytochrome p450 enzyme that catalyzes the bioconversion of dietary yellow carotenoids to red carotenoids. However, many other animal taxa display red coloration that arises from the bioconversion of yellow carotenoids to red, yet the genetic basis for this conversion remains unknown. Here, we investigated the molecular and genetic basis for population-specific levels of red coloration in the shrimp, *Halocaridina rubra*. *H. rubra* form discrete populations comprised of distinct genetic lineages that range from vibrant red to nearly translucent. We show that variation in red coloration among populations is due to differences in the accumulation of the red carotenoid, astaxanthin. Further, we show that astaxanthin accumulation is heritable and that environmental limitation of dietary carotenoids does not explain population-specific levels of coloration. Our phylogenetic analysis revealed that the transcriptomes of *H. rubra*, other crustaceans, and amphibians do not contain a paralog of *CYP2J19*. Instead, these taxa likely bioconvert carotenoids using a bifunctional hydroxylase like that found in yeast: a cytochrome p450 family 3A-like enzyme. This work is the first step in linking variation in the red phenotype of *H. rubra* to genotypic variation, providing the basis for future work including elucidating genes that function in the absorption, transport, degradation of dietary carotenoids.

105-2 WEBB, JF*; MOLNAR, EJ; NICKLES, KR; JONES, AE; CONWAY, KW; MCHENRY, MJ; University of Rhode Island, Kingston, RI, URI, Kingston, RI, Texas A&M, College Station, TX, University of California, Irvine, CA; *jacqueline_webb@uri.edu*

How to Distinguish Pattern from Chaos: Superficial Neuromasts of the Mechanosensory Lateral Line System in Fishes

The mechanosensory lateral line system (LL) of fishes mediates the detection of low frequency water flows of biotic and abiotic origin. In bony fishes, it is comprised of two types of receptor organs: 1) Canal neuromasts (CNs) in pored canals within a subset of dermatocranial bones and in the LL scales. 2) Superficial neuromasts (SNs) that occur singly, in lines or in clusters on the skin. Several methods have been used to visualize neuromasts, but recently, *in vivo* staining using fluorescent mitochondrial stains (e.g., 4-di-2-ASP) has revolutionized our ability to simultaneously image the distribution of all CNs and SNs on a fish (including dramatic proliferations of 100's - 1000's of SNs). We used 4-di-2-ASP and SEM to document SN distribution and morphology in neon tetras and allies (Fam. Characidae) and in a neon goby (Fam. Gobiidae) and to determine the size, shape and axis of best physiological sensitivity (hair cell orientation) of SNs in these taxa. We also reviewed available data on SN morphology and distribution in a range of fish taxa (Ostariophysi, Salmoniformes, Stomiiformes, Gobiiformes, Pleuronectiformes, Acanthomorpha more generally). We used these data to seek "rules" that define variation in SN morphology and the structural (and functional) organization of the lines, clusters, and large dense fields (patches) of SNs among fishes. Collectively, these data demonstrate that the distribution of SNs has been underestimated among fishes thus demanding a new context in which to address their functional role in flow sensing among fishes. Funded by URI Office of Undergraduate Research and Innovation (EJM), NSF GRFP (AEJ) and NSF Grant 1459224 (JFW).

48-2 WEBB, SJ*; SEBRIGHT, Z; TAYLOR, JRA; Scripps Institution of Oceanography, UCSD; *s3webb@ucsd.edu*

Roles pH and Temperature May Play in the Life History of the Tuna Crab, Pleuroncodes planipes

Tuna crabs, *Pleuroncodes planipes*, are unique crustaceans because adults go through both a partially pelagic phase, then a benthic phase, which occurs once they reach a certain size. This phase transition depends on growth and potentially morphological changes, like increased exoskeleton calcification. For some crustaceans, growth and calcification are sensitive to ocean pH and temperature conditions associated with climate change. Such sensitivity may be impactful for tuna crabs that get transported over long distances, frequently during warm water El Niño events, into habitats that range in these conditions. The main objective of this study was to determine how pH and temperature affect the growth and exoskeleton of *P. planipes*, and consequently their phase transition. A 10 month multi-stressor experiment was conducted on 60 adult animals (24-28mm carapace length) using a full factorial combination of local ambient pH(8.0), reduced pH(7.5), ambient temperature(12°C), and increased temperature(18°C) conditions. Molting, growth and water parameters were monitored throughout the experiment and exoskeleton morphology and composition were analyzed at the end using SEM/ EDX. Intermolt duration was shorter in warm temperature treatments, regardless of pH, but molt increment (carapace length) was greater in the cooler treatments. EDX analysis revealed no differences in %wt Ca or Mg among treatments. These results suggest that tuna crabs are robust to different pH conditions, but ocean temperature (warming) can alter growth and may alter the timing of benthic settlement, thereby impacting the duration of the transient pelagic phase upon which so many organisms depend on for food.

67-2 WEBER, AC*; GUIBINGA MICKALA, A; LIGHTEN, J; VAN OOSTERHOUT, C; ABERNETHY, KA; NTIE, S; MICKALA, P; LEHMANN, D; ANTHONY, NM; University of New Orleans, Université des Science et Techniques de Masuku, University of Exeter, University of East Anglia, University of Stirling, Agence Nationale des Parcs Nationaux du Gabon, University of Stirling; *aweber2@uno.edu*

Characterizing the class II major histocompatibility complex in wild mandrills

The major histocompatibility complex (MHC) plays an important role in adaptive immunity and mate choice in many vertebrate species. Studies in a captive group of mandrills (*Mandrillus sphinx*) have shown that female mate choice is influenced by the MHC, implying that MHC variability may have important fitness consequences. However, nothing is known about MHC variability in natural populations and how this may play a role in female mate choice. Here, we use next generation sequencing to characterize variation in the mandrill MHC class II DRB loci from 192 fecal samples collected from a wild population in Lopé National Park, Gabon. Our study revealed more than three times the allelic richness previously described in captive mandrills with variants forming two monophyletic clades. Variants in clade 1 (n=106 alleles) exhibit signals of balancing selection, as might be expected under parasite-mediated selection or disassortative mate choice. In contrast, variants in clade 2 (n=29) do not show such a signal and may represent a non-functional pseudogene that has not yet been described in non-human primates, although it has some similarity with the human pseudogene DRB9. We also observe trans-species polymorphism between mandrills and other primates, suggesting that balancing selection has maintained functional MHC lineages beyond speciation events. Future work will use these data to assess the role of the MHC in wild mandrill mate choice and fitness.

7-3 WEBER, CJ*; ZHOU, Y; LEE, JG; LOOGER, L; QIAN, G; GE, C; CAPEL, B; Duke University, Durham, NC, USA, Zhejiang Wanli University, Ningbo, China, HHMI Janelia Research Campus, Ashburn, VA, USA; *ceri.weber@duke.edu*

Temperature-dependent sex determination is mediated by pSTAT3 repression of Kdm6b

In many reptiles, including the red-eared slider turtle *Trachemys scripta elegans* (*T. scripta*), sex is determined by ambient temperature during embryogenesis. We previously showed that the epigenetic regulator, *Kdm6b*, is elevated at the male-producing temperature and essential to activate the male pathway. Here, we demonstrate that the transcription factor STAT3 is phosphorylated at the warmer, female-producing temperature, binds the *Kdm6b* locus, and acts as a repressor of *Kdm6b* transcription. STAT3 is known to be activated by signaling pathways that respond to environmental stimuli, including temperature. We propose that activation of these pathways at warmer temperatures promotes phosphorylation of STAT3, blocking expression of *Kdm6b*, thus preventing activation of the testis-pathway. Collectively, these data establish a link between temperature and transcriptional regulation of *Kdm6b* during temperature-dependent sex determination.

102-8 WEHRLE, BA*; GONZALEZ, AX; STONE, J; RANKINS, D; VUU, E; HERREL, A; TADIC, Z; GERMAN, D; UC Irvine, MNHN/CNRS, U. Zagreb; *bwehrle@uci.edu*

Do digestive enzyme activities explain increased plant digestibility in a newly omnivorous lizard?

A population of Italian Wall Lizards (*Podarcis sicula*) in Croatia has become primarily herbivorous and morphologically distinct from its source population in ~30 generations, making it a compelling example of rapid evolution. However, it is yet unclear what aspects of these shifts are fixed, and which may be due to phenotypic flexibility. There are few differences in digestive biochemistry in wild individuals measured from these populations. However, during lab feeding trials, lizards from the newly herbivorous population digested plant diets, and specifically the protein in those diets, more efficiently than did lizards from the source population. Fed insect diets, the two populations did not show differences in protein digestibility nor organic matter digestibility as a whole. What mechanism explains the newly herbivorous population's increased digestive performance of plants proteins, compared to their source population counterparts? We are currently measuring digestive enzyme activities in the pancreas and proximal intestine of lizards from both populations that have been kept on experimental diets for up to a month. On the plant diet we expect to find increased protease activity in the in the new lizard population compared to the lizards from the source population, matching the digestibility findings. Our results may shed light on what functional and performance steps can initially lead to herbivory in lizards and the importance of phenotypic flexibility in this dietary shift.

122-5 WEI, L.; REITER, K.E; MCELRATH, T.C; DUNN, A.C; ALLEYNE, M.*; University of Illinois at Urbana-Champaign, Illinois Natural History Survey; *vanlaarh@illinois.edu*

The role of cuticular diffraction gratings in beetle iridescence, wetting and friction interactions

Iridescence is found throughout the natural world, including the cuticle of many beetles (Coleoptera). Iridescence can arise through multiple mechanisms, such as parallel nanoscale ridges, slits, or fringes of the cuticle that diffract light into ordered spectra – called diffraction gratings. This iridescence has been found in many polyphagan families; however, its function in an evolutionary context is still unknown. Some iridescent beetles are known to burrow through different substrates, such as sand, leaf litter, and fungus. For these beetles, it is unlikely that iridescence has an adaptive role in visual cues. We hypothesized that diffraction gratings reduce friction for beetles traveling through various media. The friction coefficients of five pairs of closely related carabid, scarabaeid, and staphylinid, beetles (one species with diffraction grating-induced iridescence and another species without iridescence) sliding against a fibrous countersurface were measured using microtribometry in both wet and dry configurations. Iridescence was quantitatively confirmed using broad light spectroscopy. Coefficients of friction for all species increased by a factor of at least two in the wet versus the dry configuration. Goniometry (hydrophobicity) and cuticle geometry measurements were used as inputs to a friction model. The morphology of the beetle surfaces rather than the presence of a physical diffraction grating determines their wettability and friction behavior when sliding against a wet, fibrous surface. The roughness and orientation of features controls the area in contact, and dynamic changes in the contact give rise to friction.

77-2 WEITZNER, EL; PEARSON, LE; WHORISKEY, S; HARRIS, HS; WHITMER, E; BRODIE, E; TOMANEK, L; JOHNSON, S; LIWANAG, HEM*; Cal Poly San Luis Obispo, The Marine Mammal Center, The Marine Mammal Center, The National Marine Mammal Foundation; *hliwanag@calpoly.edu*

Development of Diving Capability in Weddell Seal Pups

Weddell seals (*Leptonychotes weddellii*) are among the deepest diving pinnipeds (seals, sea lions, walrus), and adult Weddell seal dive physiology is relatively well understood. However, little is known about their physiology and development as pups during nursing and the transition to independence. The aim of this study was to investigate the development of diving capabilities in Weddell seal pups throughout early ontogeny. We calculated total body oxygen stores (TBO_2) from blood and muscle sampled longitudinally at 1, 3, 5 and 7 weeks of age. These data were correlated with diving behavior measured with time-depth recorders. We found that Weddell seal pups started (at 1w) with mass-specific TBO_2 values (75.43±3.87 mL O_2 kg^{-1}) that were not significantly different from those reported for adults; this is unique among seal species. We hypothesized that TBO_2 would increase with dive experience rather than simply calendar age, but instead found that mass (r^2=0.96) and age (r^2=0.89) were more significantly correlated with total TBO_2 (P<0.0001) than time spent in water (P=0.006, r^2=0.59) or dive duration (P=0.007, r^2=0.38). Pups spent the majority of their time in the water near the surface during dependence; this 'exercise' may have signaled oxygen store development even though pups were not likely exposed to hypoxia. Relatively high mass-specific TBO_2 values may provide a 'head start' for diving and facilitate the successful transition to independent foraging in Weddell seals. Later exposure to hypoxia combined with diving experience may be the key to the subsequent increases in total TBO_2 observed in yearlings and juveniles of this species.

84-2 WELLER, HI*; LóPEZ-FERNáNDEZ, H; MCMAHAN, CD; BRAINERD, EL; Brown University, University of Michigan, Field Museum of Natural History; *hannah_weller@brown.edu*

The spandrels of Satan's perches: evidence for the co-optation of feeding traits in the convergent evolution of mouthbrooding in Neotropical cichlids

The co-opting of existing traits for new functions (exaptation) offers an overall pattern in a noisy system: of the many paths evolution can take, exaptation suggests paths of least resistance, where the traits themselves precede their novel functions. Mouthbrooding, or oral brooding of offspring, may be one such function, having evolved independently 10-14 times within cichlids alone. Mechanically, mouthbrooding involves exaptation: a feeding and breathing structure is used in reproduction. While any fish with a mouth is could mouthbrood, certain morphological traits—including some feeding adaptations—might increase mouthbrooding fitness. We hypothesized that mouthbrooding is more likely to evolve in lineages that have feeding adaptations that benefit mouthbrooding. We examined buccal morphologies in Neotropical cichlids, where mouthbrooding has evolved 5 times, 4 within winnowing (substrate sifting) clades. We found that mouthbrooders and winnowers overlapped substantially in buccal morphology. Accounting for phylogenetic and constructional constraints, species that exhibit one or both of these behaviors had larger buccal cavities, curved parasphenoids, and steeply angled vomers, while species that exhibit neither behaviors had narrow buccal cavities and flat parasphenoids. These traits may be developmental consequences of ventral orientation of the mouth for winnowing. We discuss the functional implications of these morphologies for both feeding and mouthbrooding. Our findings support our hypothesis that feeding can select for traits that can be exapted for mouthbrooding, but fully testing this hypothesis will require testing how these buccal morphologies impact both functions.

126-2 WESTERMAN , E.L*; ERNST, D.A; SULLIVAN , T.J; University of Arkansas , University of Arkansas, Gloucester Marine Genomics Institute; *ewesterm@uark.edu*

The genetic basis of mate preference learning in Bicyclus butterflies

Imprinting-like learning, where individuals learn to prefer certain characteristics in future mates based on their juvenile social environment, is pervasive across animal taxa. And, learning ability associated with imprinting-like learning is hypothesized to play a prominent role in mate preference development and sexual ornament evolution. However, the genetics that facilitate imprinting-like learning largely remain unknown. Here we utilized the butterfly *Bicyclus anynana*, a species which exhibits imprinting-like learning and has a published genome, to identify candidate genes associated with imprinting-like learning. We re-sequenced the genome of 84 *B. anyana butterflies*, half that mated with a 4-spot male in choice trials after pre-mating exposure to a 4-spot male, and half that did not. After aligning this genomic sequence to the *B. anynana* reference genome and accounting for relatedness between butterflies, we identified multiple regions in the genome highly associated with imprinting-like learning. One of these peaks of association was substantially larger and more highly associated with learning than the others, and encompasses seven genes, three of which are known to be associated with neural processing. We hypothesize that natural variation in neural processing underlies variation in imprinting-like learning, which has implications for the evolution of mating preference.

42-1 WESTNEAT, MW*; GARTNER, SM; COOPER, WJ; University of Chicago, Washington State Univ; *mwestneat@uchicago.edu*

JawsModel 2020: Tracking the Transmission of Force and Motion in Fish Cranial Linkage Systems Through Phylogenetic History

Fishes use a sensational diversity of jaw mechanisms for feeding, with more than 20 mobile skeletal elements driven by numerous muscles. How can we accurately model these systems so that morphometric data can be used to assess biomechanical traits across phylogeny? Here we integrate biomechanical modeling, geometric morphometrics and phylogenetic analysis to address questions of functional diversification in coral reef fishes. New biomechanical linkage software (JawsModel2020) for analysis of cranial linkages in fishes (from muscle contraction to bite force) allows for simulation of structure-function relationships in a wide range of taxa, using the same coordinate data sets employed for geometric morphometric shape analysis. We present detailed morphometrics, modeling, and diversification of functional traits in two reef fish families, the Labridae (wrasses) and Pomacentridae (damselfishes). Phylomorphospace plots show that damselfishes have evolved largely outside of wrasse morphospace. However, frequent convergences in shape across phylogenetic groupings within families are identified, with evolutionary rates highest in recent crown group wrasses. Linkage modeling leads to several conclusions regarding the evolution of function in reef fishes: (1) Four-bar linkage structure-to-function mapping in fishes is 1-to-1; (2) Novel linkage mechanisms in reef fishes are associated with unique cranial morphospace occupation; (3) Biomechanical traits can diverge and evolve due to linkage changes, or diverge with linkages remaining static, solely due to muscle modification; (4) Multiple mechanical variables and levels of design should be considered when defining convergent or equivalent biomechanical systems. NSF DEB 1541547

98-5 WHELAN, NV*; WILLIAMS, AS; REDAK, CA; WRIGHT, AA; GARRISON, NL; HALANYCH, KM; JOHNSON, PD; GARNER, JT; US Fish and Wildlife Service and Auburn University, Auburn University, Tuskegee University, Auburn University, Alabama Department of Conservation and Natural Resources; *nathan_whelan@fws.gov*

Habitat Preference and Impoundments Influence Population Genetic Patterns of Freshwater Gastropods

Freshwater gastropods in the family Pleuroceridae are critical components of many freshwater ecosystems in eastern North America. Pleurocerids are important nutrient cyclers and provide essential ecosystem services. As evidence of their importance to many freshwater systems, pleurocerids can comprise over 90% of macroinvertebrate biomass in some streams. Yet, pleurocerids suffer from an estimated 79% imperilment rate, with declines mostly associated with physical and chemical modification of habitats. Aside from instances of complete extirpation, how pleurocerid populations have responded to habitat degradation has been poorly studied. Moreover, we lack data on how genetic patterns differ among species that reside in springs, small streams, and big rivers. Here, we generated datasets containing thousands of single nucleotide polymorphisms (SNPs) with RAD-seq methods to examine historical responses to habitat degradation and provide comparative data for species across habitat types. In total, we sampled 12 species from 63 sites ranging from reservoirs to very small springs. We compared genetic diversity estimates among species with different habitat preferences to better understand mechanisms of genetic variation across the Pleuroceridae and to assess species boundaries of closely related species. We also examined how anthropogenic activities have influenced gene flow and genetic diversity, particularly in the context of large river impoundments. Ultimately, data generated here will aid in prioritizing conservation targets and predict potential for future declines.

116-7 WHELAN, S*; HATCH, SA; BENOWITZ-FREDERICKS, ZM; CHASTEL, O; ELLIOTT, KH; McGill University, Canada, Institute for Seabird Research and Conservation, Bucknell University, CNRS?Universitde La Rochelle, France; *shannon.whelan2@mail.mcgill.ca*

Linking female energy status to timing of reproduction in an income-breeding seabird

Food supply is a major driver of timing of breeding, yet individuals exposed to the same resource environment (e.g. shared feeding areas) often vary in their reproductive phenology. For example, individuals in poor body condition will breed later than those in good condition. At the physiological level, perception of food supply and its environmental correlates can be integrated directly into endocrine axes. Similarly, internal energetic state is incorporated into the endocrine system, inducing foraging behavior when energy levels are low. We hypothesized that if energy status limits reproduction phenology, then individual variation in reproduction phenology should correlate with net energy gains. To test this hypothesis, we conducted an experiment on female black-legged kittiwakes (*Rissa tridactyla*) nesting on Middleton Island, AK, during the prelaying period. Following a 2x2 design, we manipulated energy gains and costs via food supplementation and a short-term weight handicap (alongside controls). We measured baseline luteinizing hormone, testosterone, and corticosterone before and after a four-day GPS-accelerometer deployment, conducting a hormone challenge (luteinizing hormone releasing hormone) at the final recapture. Energy intake (supplementation) but not expenditure (handicap) influenced baseline reproductive hormones. Fed birds were less likely to forage at sea than unfed birds, and we found an interactive effect of food and handicap on at-sea activity budgets. Feeding advanced laying phenology, but short-term handicapping did not delay laying. By integrating endocrinology with movement ecology, we are able to determine how differences in energy status can lead to variation in reproductive phenology.

S5-6 WHITAKER, DL; Pomona College; *dwight.whitaker@pomona.edu*

Nature's weapons of mass reproduction: Ballistic dispersal of seeds and spores

Because plants lack locomotion, their only means of colonizing new habitats or escaping disease or predation is through seed and spore dispersal. The most effective methods for dispersal over long distances use a fluid to carry propagules. Examples of extremely long-range dispersal include pollen grains kept aloft in the atmosphere and coconuts riding ocean currents for thousands of kilometers. Despite the efficiency of using a fluid to assist in dispersal, some plants have evolved to ballistically launch their propagules at high speed. In these situations, air resistance works to decrease dispersal distance. Here we will show how the fruits of several Acanthaceae species use a dynamic method to gyroscopically stabilize launched seeds to minimize forces from air drag. We will compare this behavior across a number of Acanthaceae species and show how seed morphology and launch dynamics affect launch ranges. We will also show how this same mechanism of stabilizing disk-shaped seeds with backspin is also employed by the unrelated fruits of *Hura crepitans* (Euphorbiaceae) with a high frame rate video of its explosion. Finally, we will present the spore dispersal of *Sphagnum* moss where a vortex ring is used to efficiently carry high-drag spores to a height where they can be carried indefinitely by wind currents thus employing both low drag and high drag mechanisms to disperse its spores.

123-7 WHITE, HE*; TUCKER, AS; GOSWAMI, A; Natural History Museum, London, King's College London, London; *heather.white.17@ucl.ac.uk*

Quantification of Suture Morphology in an Ontogenetic Framework across Laurasiatheria

Cranial variation across mammals is vast and reflects their ecological diversification. Sutures perform many different functions in cranial development and function, from permitting craniofacial growth to facilitating feeding. Diversity of function is reflected in the highly variable morphology and complexity. Phenotypic variation across species is generally only studied at a fully mature ‘adult' state, with limited comparison on how such variation develops. The lack of comparative developmental data, for both cranial and suture morphology, is striking, considering the intrinsic link between evolution and development. As part of a larger study of suture and skull development and morphology in a comparative framework of mammals, we here quantify suture morphology across ontogeny, with microCT scans spanning late prenatal foetuses to adult stages for representative species of Laurasiatheria including *Manis tricuspis* and *Talpa europaea*. A 2D test dataset of extinct and extant mammals (n=79) was created to compare available methods for quantifying suture morphology, by means of complexity. From the 2D suture images, 500 semilandmarks were resampled in the R package Stereomorph to capture suture shape data. Complexity methods (fractal dimension and short-time Fourier transform with power spectrum density) were applied to the test dataset. Both methods were reliable for simpler sutures, but power spectrum density was more sensitive at detecting differences in sutures with complex morphology. Following this result, we quantified suture complexity and morphology across representative species of Laurasiatheria in an ontogenetic framework, by applying the tested power spectrum density method, with the goal to understanding how development generates suture morphological disparity.

120-2 WHITE, CH*; LAUDER, GV; BART-SMITH, H; University of Virginia, Charlottesville, Harvard University, Cambridge; *chw8hq@virginia.edu*

Tuna robotics: impact of body flexibility and fin-fin interactions on swimming performance of a new tuna-inspired robotic platform

The performance space of fish-like robotic swimmers is largely confined to tail beat frequencies measuring less than 2 Hz. However, tuna and scombrid fishes are capable of frequencies in excess of 20 Hz. We design a new tuna-like robotic experimental platform that addresses this disparity in frequency and enables testing over a frequency range comparable to biology. The new platform's morphology is closely modeled after yellowfin tuna (Thunnus albacares) by incorporating data from computed tomographic (CT) scans and reference images of yellowfin tuna. Propulsion is provided by a 12V DC motor in a waterproof housing of Nylon PA12 plastic 3D printed using 60μ selective laser sintering (SLS). The motor shaft is waterproofed with a stuffing tube design. Measuring 255 mm in total length, this tuna-like system includes first and second dorsal fins and an anal fin. All fins are removable for testing with a snap-in magnetic design to assess fin-fin interactions between the dorsal/anal fins and the caudal fin. The body is 3D printed with flexible joints that can be varied in number and the extent to which they permit lateral motion to explore the impact of body flexibility on swimming performance. For each joint configuration, the performance metrics measured include swimming speed, power, and thrust. Midline kinematics and flow field analysis from particle image velocimetry (PIV) visualization are also analyzed. These results are compared against biological data to understand the role of body flexibility during high-frequency swimming.

30-6 WHITE, CF*; WHITNEY, NM; WEBER, DN; FRAZIER, BS; Harvard University, Cambridge, MA, New England Aquarium, Boston, MA, Texas A&M, Corpus Cristi, TX, Department of Natural Resources, Charleston, SC; *connor_white@fas.harvard.edu*

Survival and Swimming Behavior of Red Drum (Sciaenops ocellatus) Following Recreational Capture and Release

Red drum (*Sciaenops ocellatus*) is a highly targeted recreational species, with 95% of captured individuals released alive. However, it is uncertain how many of these released fish survive, as many experience barotrauma as part of capture. Thus, we replicated recreational practices to (1) estimate post-release survival and sub-lethal impacts of capture on red drum and (2) experimentally test the effect of common release practices on survival and behavior. To do so, captured individuals (n=54, TL = 93 ± 7.3 cm) had an acceleration data logger(monitoring duration 39 ± 24 hr) affixed to their dorsal musculature and their physiological status was assessed using an iStat blood gas analyzer in the field. Individuals were then released by one of three treatments: a descending device (SeaQualizer, n=13), venting their swim bladder (n=18), or a control of no treatment (n=23). Of the 46 recovered data loggers, only two fish experienced mortality events; a gut-hooked fish that received no treatment (moribund: 102min PR) and a descended fish that likely was predated upon 124 minutes after release. However, recreational capture was stressful for fish, as longer fight times were associated with higher lactate concentrations (p=0.01) and lower blood pH (p=0.022). Upon release individuals had 60% higher activity levels (p=0.001) and displayed twice as much vertical displacement (p=0.001) compared to 24 hours after release. Both vertical displacement and activity level displayed similar patterns, decreasing over the first 10 hours after release before reaching a baseline level. Release treatment also had no apparent sublethal effects on fish, as activity level (p = 0.17) or vertical displacement (p = 0.14) remained the same between treatments.

3-6 WHITEHEAD, JG*; WORRELL, TA; SOCHA, JJ; Virginia Tech; *whijo23@vt.edu*

Influence of approach trajectory on water landings in mallards

Studies of landing in birds have focused on perch landings involving short flights within a controlled laboratory. However, birds demonstrate the ability to land under a diverse set of conditions, including the ability to land on water, a fluid substrate. Landing on water enables birds to dissipate the energy of collision through skimming after impact. In this study, we examined the relationship between distance skimmed and impact speed, impact angle, and mean approach angle (the mean trajectory angle from a given landing). Landing mallards were recorded in the wild with a three-camera array (GoPro HERO4 Black) with 4k resolution at 30 fps. The array was calibrated with a 0.94 m wand and an audio synchronization through Argus 3D tracking software. Filming was conducted with wind speeds less than 3.3 m/s, in the months of October through May, 2017-2019. From 177 digitized landings, a diverse range of kinematics was documented, with impact speeds of 5.02 ± 1.36 m/s (mean ± SD) [range, 1.76 m/s, 8.48 m/s], impact angles of 14.8 ± 10° [0.6°, 59.9°], and mean approach angles of 8.6 ± 6.3° [-0.4°, 36.7°]. After impact, mallards skimmed a distance of 2.17 ± 1.36 m [0 m, 6.04 m]. Impact speed, impact angle, and mean approach angle are all significantly correlated to the distance skimmed after impact. However, a general linear regression model utilizing those kinematic features only accounts for approximately 25% of the variation seen in the distance skimmed, with impact speed accounting for the greatest portion (22%). This low value for the sum of the coefficients suggests much of the variation observed is the result of other factors including rotational movements of the body on impact, which may change the drag profile of the duck at the air-water interface.

11-5 WHITFORD, MD*; FREYMILLER, GA; HIGHAM, TE; CLARK, RW; San Diego State University, University of California, Riverside; *mwhitford@ucdavis.edu*

The Effects of Temperature on the Predatory and Defensive Strikes of Rattlesnakes

Locomotor performance is heavily influenced by body temperature due to the link between temperature and muscle physiology. As temperature influences the performance of endotherms and ectotherms asymmetrically, temperature can play an important in role in determining the outcome of predator-prey interactions. Rattlesnakes (*Crotalus* spp.) are a widespread genus in North America and are active during day or night, so their strike performance may vary substantially across seasons and time of day as available environmental temperatures change. Additionally, as rattlesnakes are an abundant meso predator, being a major predator of small mammals and prey resource for many large endothermic predators (large mammals and birds), temperature can influence both their ability to capture prey and their ability to avoid predators. Here, we studied the effects of temperature on the predatory and defensive strikes of rattlesnakes. We found that the kinematics of defensive strikes were positively correlated with body temperatures, however, temperature was less influential in modulating the kinematics of predatory strikes both in the field and the lab. This research provides valuable insight into the potential for temperature, and possibly climate change, to influence large-scale ecological processes that are mediated by endotherm-ectotherm predator-prey interactions.

97-4 WHITLOW, KR*; ROSS, CF; WESTNEAT, MW; University of Chicago; *kwhitlow@uchicago.edu*

Strike biomechanics in Polypterus bichir described with XROMM: implications for actinopterygian feeding evolution

Our understanding of the evolution of skull kinesis in fishes requires detailed analysis of feeding in living polypterids, a key lineage due to their phylogenetic position as the earliest-branching extant actinopterygian group. *Polypterus* skulls contain an upper jaw fused to the neurocranium, eliminating one axis of cranial kinesis utilized by teleosts and *Amia* in generating suction. However, their skulls remain highly kinetic, using dorsal, ventral, and lateral expansion to generate suction. Additionally, mechanisms of lower jaw depression and the degree to which pectoral girdle and ceratohyal retraction are transferred to the lower jaw through the mylohyoid ligament are poorly understood in this species. This study describes the major patterns of 3D mechanics driving buccal expansion and suction feeding in *Polypterus bichir* using X-Ray Reconstruction of Moving Morphology (XROMM). Cranial elevation peaks early in the strike, followed shortly by maximal lower jaw rotation, then cleithral and hyoid rotation, which occur nearly synchronously when variables are measured relative to the body axis. As in many other suction feeding fishes, opercular abduction undergoes the final kinematic peak of the cranial elements, maintaining the anterior to posterior movement of water into and through the mouth. Results show substantial cleithral rotation, largely concurrent with ceratohyal rotation and jaw opening, suggesting a central role of the pectoral girdle in jaw opening and suction generation. This pectoral girdle – hyoid bar – lower jaw depression mechanism is likely driven by the hypaxial musculature and may be the ancestral condition for ray-finned fishes.

112-1 WILCOXEN, TE; SPENCE, JM*; Millikin University ; *twilcoxen@millikin.edu*

Effects of cypermethrin on neurophysiology, development, and behavior of Cuban treefrog (Osteopilus septentrionalis) and American bullfrog (Lithobates catesbeiana) tadpoles.

Cypermethrin is a pesticide designed to disrupt the nervous system of invertebrates, though vertebrates may also be affected. We exposed Cuban Treefrog (*Osteopilus septintrionalis*) and American Bullfrog (*Lithobates catesbeiana*) tadpoles to cypermethrin at two different concentrations and recorded neurophysiological and behavioral metrics among groups. We also measured plasma corticosterone levels in the bullfrog tadpoles at two time points. Tadpoles exposed to cypermethrin were found to be smaller, less developed, and hyperactive compared to a control group, despite showing no signs of altered acetylcholinesterase levels. The behavioral differences combined with elevated corticosterone levels in the bullfrog tadpoles exposed to cypermethrin demonstrate that cypermethrin is a stressor for these animals even though it may not have direct impacts on the nervous system.

99-6 WILKEN, AT*; MIDDLETON, KM; SELLERS, KC; COST, IN; HOLLIDAY, CM; University of Missouri; *atwxb6@mail.missouri.edu*

Functional Morphology of the Palate of Varanus exanthematicus and its Significance for the Evolution of Cranial Kinesis

Although many species of vertebrates evolved feeding behaviors that employ cranial kinesis, little is known about the loading environment of the palate and other parts of the suspensory apparatus responsible for this movement. Additionally, the role protractor muscles play in controlling palatal excursion or insulating the braincase and sensory capsules via palatocranial joints is challenging to test in vivo and equally unclear. We explored the morphology of jaw musculature, kinetic joints and cranial bones using diffusible iodine-contrast CT and histology of *Varanus exanethematicus*, a modestly kinetic anguimorph lepidosaur. DiceCT imaging and fiber tracking analysis shed new light on the muscular anatomy and architecture of these muscles. Finite Element Modeling was employed to test the effects of muscle activation and joint material properties on the loading environment of the palate, braincase, and skull. We found different joint material properties have only minor effects on the loading environment of the skull. Complex interactions between m. levator pterygoideus and m. protractor pterygoideus work to stabilize the palate about the palatocranial joints and ultimately diminish the strains experiences by the braincase. The tubular cross-section and second moment properties of the pterygoid bone reflect l the bending and torsional environment developed during biting. These data will inform future studies of cranial function and illustrate how morphological complexity of cranial bones, joints, and muscles evolve in different lineage of lepidosaurs and reptiles in general. New understanding of the biomechanics of the jaw muscles, bony linkages and connecting joints reveals a better understanding of skeletal adaptation, physiology and evolution.

133-5 WILLIAMS, CD*; KNIJNENBURG, TA; Allen Institute for Cell Science; *cdavew@alleninstitute.org*

Spatial reorganization and clustering during the formation of myofibrils

Muscle cells generate an entirely new organelle as they differentiate from their stem cell precursors. The structures that emerge from this process are responsible for the production and transmission of force from the molecular to the organismal scale, and for the specialized adaptation of the resulting fibers. The transition from pre-myofibril to developing and mature myofibril is mechanically regulated. The mechanical context, e.g. surrounding tissue stiffness and active forcing of cell edges as surrounding cells contract, partially control the reorganization of the actin/myosin/cross-linker bundles. The ordering of these pre-fibrils is in contrast to similar structures present in other load-bearing or motile cells. Non-muscle stress-fibers contain many or most of the same constituent proteins but never transition to the stable crystalline order seen in developing myofibers. The Allen Institute for Cell Science is producing a high-throughput dataset that explores these transitions as human induced-pluripotent stem cells differentiate into derived-cardiomyocytes. We develop and present a spatial model, parameterized by this high-throughput imaging, that tracks the force and diffusion mediated rearrangement of proteins within a developing myofibril. This model treats each protein as an object with distinct dimensions, stiffnesses, energy-dependent kinetics, and connectivities. Comparison of large-scale runs to structure-organization metrics derived from the Allen Institute for Cell Science's growing muscle-differentiation image corpus allows us to characterize the emergence of sarcomereic organization.

110-1 WILLIAMS, KL*; EVANS, KM; SIMONS, AM; University of Minnesota and University of Minnesota Bell Museum, Brown University; *will5761@umn.edu*

The morphology of tooth replacement in Salariin Combtooth Blennies (Blenniiformes: Blenniidae: Salariini)

Historically, modes of teleost tooth replacement are classified as either intraosseus, wherein replacement teeth develop in sockets within the bone of attachment, or extraosseous, where replacement teeth develop within soft tissue outside the bone of attachment. However, recent work suggests that these modes of tooth replacement are extremes on a continuum and therefore understate the complexity of teleost tooth replacement. Salariin combtooth blennies (Blenniiformes: Blenniidae: Salariini) are a clade of teleost fishes that demonstrate an unusual mode of tooth attachment in which functional teeth are attached via loose connective tissue that may extend laterally beyond the jaw margins. Although tooth attachment has previously been described, these studies were limited by available technology. We use a range of methods including histology, SEM, microCT scanning and clearing and staining to ask two questions: **1)** How are functional teeth replaced in the salariin blennies? **2)** Do salariin blennies provide further evidence for a continuum of teleost tooth replacement modes? We find that replacement teeth develop and move labially through a matrix of highly vascularized epithelial and connective tissue, via a permanent, discontinuous dental lamina, to the functional tooth position. Most species exhibit teeth that at no point in development make contact with the oral jaw bones, and in some species, teeth are replaced within lip tissue lateral to the oral jaws. Salariin teeth are replaced extraosseously but their mode of attachment is unique, providing further evidence for a continuum tooth replacement classification model for teleost fishes.

25-6 WILLIAMSON, CJ; SPELT, A; WINDSOR, SP*; University of Bristol; *cara.williamson@bristol.ac.uk*

Are complex wind fields beneficial for soaring? An urban gull's perspective

Wind interactions in urban spaces generate complex flow patterns that are difficult to predict, however these heterogeneous wind fields may offer considerable opportunities for energy harvesting for flying animals. Applying Cost of Transport (CoT) theory to flight dynamics equations for flight through a wind field indicates that with the right airspeed and trajectory adjustments it is possible to harvest energy from spatiotemporal wind gradients. We tracked 11 urban nesting lesser black-backed gulls, *Larus fuscus*, using GPS units over 2 years as they flew through urban environments. The loggers collected a GPS fix up to every 4 seconds along with a 1 second burst of acceleration data; allowing us to determine the gulls' trajectories and flight modes. Our initial studies found the gulls flew at velocities predicted by CoT theory in flapping and soaring flight. Furthermore, we observed the gulls perform a soar strategy not explained by static soaring techniques and hypothesized that the gulls were taking advantage of spatiotemporal gradients to soar. We tested this hypothesis using a 4D path planner in CFD generated city wind fields. A cost function was used that combined CoT velocity optimization with a flight dynamics model which included energy expenditure estimates based on Basal Metabolic Rate ratios for flapping and soaring flight. The simulated commuting flights gave trajectories with gradient soaring flight traits which corresponded to those seen in the gull flight paths. This suggests that complex wind fields, such as those present in urban environments, could provide ample opportunities for energy harvesting, and that soaring is not just limited to more structured wind fields, such as thermals or shear layers. This offers inspiration for the development of wind-aware flight control schemes to increase the range and endurance of unmanned air vehicles.

S9-4 WILSON, RS*; PAVLIC, T; WHEATLEY, R; CAMERON, SF; The University of Queensland, Arizona State University; *r.wilson@uq.edu.au*

Using performance to predict the survival of threatened mammals

More than a third of all modern extinctions have occurred in Australia and the ongoing loss of these distinctive species threatens to diminish global biodiversity. Half of Australia's endemic land mammal species are now threatened or extinct, and most ecologists agree that this is due mainly to an interaction between habitat simplification and introduced predators. Understanding and predicting extinction risk relies on our ability to identify when, where and how predators attempt to capture their prey, and how and whether prey can escape them. When predators encounter prey, the success of each (i.e. capture versus escape) is defined by the physical and performance attributes of both, including traits such as body size and speed or agility. However, most studies of performance focus on the physiology and biomechanics of movement of species' in isolation rather than relative performances between predators and their prey. Therefore, conservation ecologists and managers lack the ability to predict which animals are likely to survive encounters with predators and why. Our work is attempting to address this gap by developing and testing a mathematical framework that predicts the survival of prey, based on their capacity to escape specific predators in different habitats. In this talk I will discuss the development of our model and progress with the testing of the model at our northern Australian field site on Groote Eylandt using studies of two marsupial species (northern brown bandicoot and northern quoll) that have undergone extensive decline across their range.

23-5 WILSON, LE*; CURLIS, JD; LONSDALE, G; COX, CL; Georgia Southern University, University of Michigan, University of Plymouth, Florida International University; *lw16271@georgiasouthern.edu*

The role of sympatry on predator-based selection on coral snake mimicry components in the montane tropics

A fundamental goal of biological research is to understand the forces that drive the evolution of phenotypic diversity such as in mimicry systems. In particular, understanding how selection acts upon the signal components of mimicry can give insight into how mimicry has evolved. We study coral snake mimicry, where brightly colored and venomous coral snakes are imitated by harmless snakes. Previous research in temperate zones has found that components of coral snake color pattern must be precise in edge sympatry, may be relaxed in deep sympatry, and may not convey a fitness advantage at all in allopatry. However, we know relatively little about the evolution of signal components in montane tropical ecosystems, which are ideal for studies of sympatry and allopatry because elevation creates a mosaic of sympatry and allopatry. We tested which mimetic signal components are important for deterring attacks in sympatry and allopatry with coral snakes in a tropical cloud forest in Honduras. We placed 240 plasticine models that were either brown, white and black, red and black, or white, red, and black (mimetic) in sympatric and allopatric sites. We found that attacks by birds, but not mammals, were highest at the two sympatric localities. Models with either bands or red color were attacked with less frequency by birds, but not mammals, than other models at one sympatric site. These results lend insight into how geographic range and elevation may alter selection for signal components of coral snake mimicry systems in the tropics as well as affect the broader processes that generate and maintain phenotypic diversity.

136-5 WINCHELL, CJ*; LEE, DT; REYES-RIVERA, J; RODRIGUEZ, A; TORRES, MM; WEISBLAT, DA; UC Berkeley; *cjwinchell@berkeley.edu*

Functional analysis, by CRISPR mutagenesis, of genes in the atomized Hox cluster of the leech Helobdella austinensis

Leeches are active epibenthic predators or ectoparasites; in contrast, their ancestors and close extant relatives (oligochaetes) are infaunal detritus feeders. In the transition from oligochaetes, leeches evolved novel features, e.g., determinate growth (32 segments, all arising in embryogenesis), anterior and posterior suckers, and a specialized midgut with segmental ceca. Leeches and oligochaetes also exhibit massive genomic changes (gene loss & duplication, loss of macrosynteny) relative to other animals. For example, the leech Hox cluster is highly atomized, and has multiple gene losses and duplications relative to the ancestral lophotrochozoan. Has Hox cluster disorganization enabled new regulatory interactions and functions for these transcription factors? Do these molecular novelties contribute to the morphological novelties in leeches? We use the tractable leech species *Helobdella austinensis* as a model in which to characterize the expression, function and regulation of duplicated and single-copy Hox genes. In contrast to arthropods and vertebrates, CRISPR-induced Hox mutants in leech do not show overt homeosis (altered segment identity). Rather, we observe: defects in gut and sucker formation (for *post2a*, *post2c*, *lox4b*); late-embryonic edema (for *lox5*), possibly due to a failure in kidney development; an embryonic-lethal phenotype during epiboly (for *hox3*), perhaps caused by duplication of segmentation stem cells (teloblasts); and new gene expression patterns and regulatory interactions compared with those known in polychaetes. Our results reveal how Hox-related developmental mechanisms may have contributed to annelid body plan diversification.

26-1 WINGFIELD, JC*; REID, AMA; PEREZ, JH; BISHOP, VR; KRAUSE, JS; MEDDLE, SL; University of California, Roslin Institute University of Edinburgh, University of Glasgow, University of Nevada Reno; *jcwingfield@ucdavis.edu*

Divergence of Hypothalamic-pituitary-gonadal (HPG) Axis Gene Expression and Testosterone in Migrant and Resident Female White-crowned Sparrows

Photoinduction of the hypothalamic-pituitary-gonadal (HPG) axis in seasonally breeding animals activates the reproductive system but precise timing of breeding and sex steroid production are controlled by local environmental information. We aimed to understand functional regulation of the HPG axis by changes in gene expression and synthesis of testosterone in female migrant and resident subspecies of white-crowned sparrow. We hypothesized that regulation of the HPG axis would differ between residents and migrants during breeding and molt, but not during winter. Plasma testosterone was higher in migrants compared to residents during egg lay and incubation. Hypothalamic expression of estrogen receptor was down-regulated, while androgen receptor, gonadotropin inhibitory hormone (GnIH), aromatase and 5 -reductase were up-regulated in migrants compared to residents. No differences were observed between subspecies in gene expression for luteinizing hormone receptor, follicle stimulating hormone receptor, side chain cleavage enzyme, steroidogenic acute regulatory protein, 3 -hydroxysteroid dehydrogenase, or aromatase. Ovarian gene expression associated with inhibiting the reproductive axis. GnIH, mineralocorticoid receptor, glucocorticoid receptor and 11 -hydroxysteroid dehydrogenase 2 were higher in migrants but not residents during breeding. These data suggest nesting onset may result in increased plasma testosterone regulated by differential gene expression in the hypothalamus and increased sensitivity to stress at the gonad level.

25-7 WISSA, A/A; University of Illinois Urbana-Champaign; *awissa@illinois.edu*

Aerodynamic Characterization of a Leading-Edge Alula-Inspired Device

Even though Unmanned Aerial Vehicles (UAVs) operating at low Reynolds numbers are becoming common, their performance and maneuverability are still greatly limited due to aerodynamic phenomena such as stall and flow separation. Birds mitigate those limitations by adapting their wings and feather shapes during flight. Equipped with a set of small feathers, known as Alula, located near the leading edge and covering 5% to 20% of the span, bird wings can sustain the lift necessary to fly at low velocities and high angles of attack. In this presentation, an alula-inspired leading edge device is installed on a high-lift airfoil and a moderate aspect ratio wing. Wind tunnel experiments are conducted at post-stall and deep-stall angles of attack and at Reynolds numbers of 100,000 and 135,000. Experimental results including integrated force measurements and hot-wire anemometry are presented. The presentation examines the distinctive effects of the geometric parameters of an alula-inspired leading-edge device (LEAD) on the aerodynamic performance of both the airfoil and the finite wing are discussed. Results show that the LEAD affects the airflow in two fundamental ways. First, it increases the capability of the wing to maintain higher pressure gradients by modifying the near-wall flow close to the leading-edge. Second, it generates tip vortices that modify the turbulence on the upper-surface of the wing, delaying flow separation. Post stall lift improvements of up to 32% are reported, confirming that the LEAD is a post stall and a three-dimensional device. Results show that these lift improvements are more sensitive to the LEAD relative angle of attack and root location than to the LEAD tip deflection angle.

126-3 WOFFORD, SJ; Behavioral and Sensory Ecology Laboratory, Dept of Biology, Jacksonville State University; *swofford@jsu.edu*

Urine for a fight: Sex-based differences in crayfish contest signaling

Competition for resources can result in physical contests which are energetically costly and potentially injurious. Organisms with a strategy to assess when costs of a contest have outweighed the benefit of a resource can minimize overall costs that could negatively impact fitness. Males and females of a species incur different types of fitness costs due to reproductive differences, and evidence suggests that these differences can influence contest behavior and persistence. Longer contests equate to greater energy expenditure and risk of injury which could be more costly to female opponents. Consequently, male and female differences in assessment strategies present an ecologically relevant exploration of the context dependence of assessment. Using crayfish as a model organism, we have found that male and female crayfish likely differ in the information used to determine contest persistence and intensity. We first explored the assessment strategy in place for same-sex and mixed-sex dyads and found that mixed-sex contests differed from same-sex contests. While both male and female same-sex contests showed strong evidence for a self-assessment strategy, mixed-sex opponents had no obvious strategy in place. Subsequent trials limited the availability of a chemical signal during mixed-sex contests and revealed varied impacts for males and females. While contest outcome was simply a function of size, contest duration was dependent on both opponent size and the accessibility of chemical information. We suggest that chemical information is equally important for male and female crayfish in contest assessment but the information contained in or conveyed by the signal likely differs.

75-3 WOLD, ES*; ROBERTS, TJ; SLEBODA, DA; Brown University, Providence RI; *ethan_wold@brown.edu*

Osmotic engine drives shortening in passive skeletal muscle

Skeletal muscle, like most biological tissues, is primarily made up of fluid. This fluid is rarely considered a mechanical component of muscle, but recent work suggests that it may be a determinant of basic muscle properties. We have shown previously that an isolated muscle bathed in dilute solution takes on water and swells. If held at constant length during this process, it develops greater passive tension over time. This phenomenon can be replicated by a model of a fluid-filled cylinder surrounded by a fiber-wound matrix, and we have proposed that a similar interaction of fluid pressure and the collagenous extracellular matrix influences passive force development in muscle. We explore this hypothesis further by measuring shape changes in isolated bullfrog semimembranosus muscle held at constant tension by a servomotor. When bathed in hypotonic solution 20% of isotonic, muscles swelled (as measured by an increase in muscle width) and shortened. Over time, shortening was proportional to the increase in width. Although the work done was small compared to an active muscle, the forceful shortening demonstrates that passive skeletal muscle is capable of acting as an osmotic engine, converting osmotic potential to mechanical work. Returning muscle to an isotonic solution reduced muscle width and was associated with re-lengthening. Length changes observed in muscle that was held at a low force were greater than those at high force, and a mathematical model inspired by human-engineered McKibben pneumatic actuators yields similar outcomes. These results suggest another parallel between biological muscle and McKibben actuators, and give support for the notion that muscle shape change is influenced interactions between extracellular matrix collagen and intracellular fluid.

92-3 WOLF, SE*; BELTRAN, SE; SANDERS, TL; ROSVALL, KA; Indiana University, Dominican University, Oklahoma State University; *wolfsae@indiana.edu*
Telomere protection mechanisms and adaptive organismal responses to early postnatal stress
Telomeres are the guanine-rich, protective ends of chromosomes that shorten with exposure to stressors and consequently, may link early life stress with long-term effects on phenotypic qualities. However, recent findings highlight gaps in our understanding of telomere protection mechanisms (e.g., antioxidants, DNA-binding proteins) and their role in minimizing stress-induced telomere loss. Here, we ask how an acute stressor influences physiology and telomere dynamics in free-living nestling tree swallows (*Tachycineta bicolor*), with a focus on molecular mechanisms that protect telomeres from shrinkage or promote recovery (i.e., elongation) following stress. During the peak of nestling growth, we injected mothers with lipopolysaccharide, which led to a temporary (~24h) decrease in chick provisioning. 24 hours and 1 week following treatment, we sampled chicks to quantify acute and lasting effects of food limitation on telomere-related processes in a select set of neural and peripheral tissues. One week after treatment, we saw changes in telomere dynamics, stress reactivity, and gene expression of telomere regulatory processes (i.e., antioxidants, POT1) in blood. Now, we explore how telomere regulatory mechanisms respond immediately after 24 hours of fasting, and the degree to which protection mechanisms vary by tissue. Results will shed light on the causes and consequences of variation in telomere dynamics and emphasize the potential role of telomere protection mechanisms in adaptive responses to stress.

106-8 WOLF, CJ*; CHEVIRON, ZA; University of Montana, Missoula, MT; *colejwolf@gmail.com*
Seasonal Variation of Body Composition in Deer Mice (Peromyscus maniculatus)
Body condition, an estimate of an animal's fat reserves, is frequently used to assess population health and habitat quality, but few studies have attempted to link condition to individual survival. In deer mice, cold-induced summit metabolic rate is positively correlated with survival. Because fats are the primary fuel source for thermogenesis in rodents, an individual's fat reserves (i.e., condition) may also be related to survival. We used a mark-recapture study to examine: 1) the relationship between condition and survival and 2) seasonal variation in body condition, activity levels, and field metabolic rate. We surveyed deer mouse populations on two 1-hectare grids in western Montana for four nights each month from May through November in 2018 and 2019. Body composition (percent fat and lean mass) was assessed via quantitative magnetic resonance (QMR). We did not find any association between percent body fat and survival rates over the sampling period. Female mice had higher percent body fat than males, but both sexes carried significantly less fat in August and September than in other months. Since this period represents the peak and tail of the dry season, this pattern may be linked to the hot and dry conditions of late summer. Deer mice are known to reduce aboveground activity when conditions are unfavorable, which could force individuals to rely on fat reserves in lieu of foraging. However variation in nightly movement rate was not significantly associated with month or percent fat – suggesting a different mechanism may be driving this seasonal reduction in fat reserves.

S4-5 WOLFNER, MF; Cornell University; *mfw5@cornell.edu*
The female side of the male x female interactions that modulate sperm competition and reproduction
Reproductive interactions between males and females integrate molecules, cells, behaviors, and physiology from both partners. In sperm competition, attention has been paid to the evolution of male features to improve their success, such as faster sperm, more sperm, and composition of seminal plasma. Although the female is not ‘passive' in the outcome of sperm competition, the nature of her genes and molecules that regulate sperm outcome is unknown. By a GWAS based on variation in Drosophila female contributions to sperm competition outcomes, we (Chow et al., 2013 Genetics) identified SNPs whose presence in the female genome modulated the outcomes of sperm competition. Recently, we (Chen, Delbare, White et al., 2019 Genetics) tested directly for the action of genes defined near those SNPs in sperm competition outcome. Eight genes showed such effects, and five of these are neurally-expressed. I will describe these results, and recent data from D. Chen that show that at least one of these neural classes participates in modulating sperm competition outcomes. Another phenomenon involving female-male cross-talk concerns how seminal proteins interact with females' physiology in Drosophila and mosquitoes; examples will be presented. These interactions are often discussed in terms of the male ‘manipulating' the female. I will suggest that in some cases one could consider that the female is, instead, ‘using' the male to activate certain of her physiological pathways, when it is beneficial to her that they be activated. [Sperm-competition work is in collaboration with A. Clark, mosquito work is in collaboration with L. Harrington; all studies described were funded by NIH.]

46-1 WOLLESEN, T*; MUSSER, J; BERTUCCI, P; ARENDT, D; European Molecular Laboratory, Heidelberg, Germany; *tim.wollesen@embl.de*
Single Cell RNA-sequencing reveals molluscan cell types and sheds light on the evolution of a complex bilaterian body plan
How did the vast diversity of cell types arise during evolution and how are cell types related to each other? Addressing these questions, we study representatives of the phenotypically diverse superphylum Lophotrochozoa with clades as different as mollusks or annelids. The polyplacophoran mollusk *Acanthochitona crinita* exhibits ancestral molluscan and bilaterian traits. Its trochophore larva is a mosaic of embryonic and adult features such as seven shell plates, an apical organ, a ciliary band, a creeping foot, and a differentiated nervous system. In order to investigate the cellular organization of these ancestral traits we have conducted whole-body single cell transcriptomics on trochophore larvae using 10x genomics and Next-Seq technology. Approximately 8000 cells with 8000 mean reads per cell were obtained and more than 60 different cell types revealed which were localized via *in situ* hybridization experiments. Besides endodermal clusters, we identified mesodermal cell types giving rise to the complex polyplacophoran musculature. In addition, several ectodermal cell types including sensory cells, other neurons, and epidermal cells were found. Notably, cell types forming the shell fields and the surrounding spicules cluster together with neuronal cell clusters suggesting a shared evolutionary history. By comparing our data to those of other lophotrochozoan representatives we reveal putative homologous cell types. Our data lay the foundation for tracing the evolution of cell types and cell type families across Lophotrochozoa and Bilateria.

S10-11 WOMACK, MC; National Museum of Natural History, Washington, DC; *molly.womack@usu.edu*
Disentangling intrinsic and extrinsic factors underlying anuran postcranial skeleton evolution
Many extrinsic factors (habitat, biotic interactions, etc.) and intrinsic factors (phylogenetic history, size constraints, etc.) affect the morphological evolution of a lineage, making it difficult to disentangle the effects of any particular factor on trait evolution. Frogs and toads (anurans) present a unique opportunity for studying how intrinsic and extrinsic factors contribute to morphological and functional diversity because they are specious (over 7,000 species), distributed worldwide, vary in body size, and have frequently and independently invaded various microhabitats (aquatic, arboreal, terrestrial, etc.). Using microCT data from over 250 species across all families, we first correlate postcranial skeleton evolution with phylogeny, body size, and microhabitat at a macroevolutionary scale spanning 200 million years. We then use existing performance data to pinpoint skeletal features affecting locomotion and other functions. Finally, we lay out hypotheses to be tested via developmental studies, mechanical modeling, and performance data that will inform why skeletal evolution varies among clades and how skeletal variation promotes functional and ecological diversification in anurans.

20-5 WONG, S*; BIGMAN, JS; DULVY, NK; Simon Fraser University, Burnaby, Canada; *serenaw@sfu.ca*
Ontogenetic scaling of gill area and brain size between two populations of blacktip shark (Carcharhinus limbatus)
Temperature underlies physiological and ecological variation among populations. For example, temperature is a key determinant of water oxygen availability, affecting metabolism, life histories, and morphology in fishes. Since gill area (GA) relates to oxygen diffusion and brains are one of the most metabolically costly organs, we hypothesize that populations at higher environmental temperatures will have faster life histories, larger GA relative to body size, and smaller brains relative to body size. Here, we ask whether GA and brain size vary between two populations of blacktip sharks (*Carcharhinus limbatus*) living in different environmental temperatures. However, because GA and brain size change with body mass throughout sharks' lives, these traits must be studied in a scaling context. We predicted that the slope values for both GA and brain size would be similar for the two populations, but that the warmer population would have a larger GA and a smaller brain for a given body size. Gill area and brain mass were measured on individuals from the cooler South Atlantic Bight and the warmer Gulf of Mexico. We found that the Gulf population had a smaller relative brain size than the Atlantic population when we compared immature individuals, but also a smaller relative GA. Finally, both brain mass and GA scaled more steeply with body mass in the Gulf population. These results suggest that temperature influences the scaling of GA and brain mass between populations of blacktips. Investigating how GA and brain size scale between populations with different life histories and environments helps provide a better understanding of the evolutionary effects of environments on two key organs, as well as how environment and physiology impact metabolism and life histories.

91-2 WOOD, T/C*; MOORE, P/A; Bowling Green State University and University of Michigan Biological Station; *tcwood@bgsu.edu*
Chemical Landscapes of Fear: Crayfish can Determine the Degree of Predatory Threat by Olfaction Alone
Encounters between predators and prey lead to capture and consumption of the prey or a nonlethal avoidance response when the prey changes its behavior to evade the threat. Either outcome is costly for prey. However, not all predators represent equal threats, especially when predators are gape limited. Prey solve this problem by obtaining information about a predator from a variety of sensory cues that they use to assess risk, to avoid responding to nonthreatening predators. Chemical cues in the form of predator odors provide information about the predator's species identity, health, satiation state, and previous dietary components. Odors also indicate the size of the predator, which could inform prey if a predator poses a threat relative to their own body size . Rusty crayfish (*Faxonius rusticus*) were exposed to odor cues produced by two gape limited predatory fish, Largemouth Bass (*Micropterus salmoides*) and Rainbow Trout (*Oncorhynchus mykiss*) across a gradient of relative size relationships. Crayfish consumed more macrophytes when exposed to odors from bass that were large relative to the crayfish. There was no change in macrophyte consumption by crayfish exposed to trout odors along the same relative size gradient. Foraging effort and shelter use behaviors of the crayfish were also impacted by odors from predators that were large relative to the size of the prey. Thus, crayfish can extract size information from predator odor cues and use this information to determine if the predator represents a threat relative to their own body size. However, the responses are also species specific, which further supports the hypothesis that prey assess risks relative to the threat posed by individual predators.

90-6 WOOD, H.; Smithsonian Institution; *woodh@si.edu*
Reverse engineering the "trap-jaw" mechanism in spiders (Araneae, Mecysmaucheniidae)
Trap-jaw spiders (Mecysmaucheniidae) have been shown to have ballistic, high-speed "jaw" movements that are the fastest known arachnid movements to date. Within the family there is considerable interspecific functional diversity, with the fastest species moving their "jaws" two orders of magnitude faster than the slowest species. Phylogenetic analysis has revealed that the four fastest lineages do not form a monophyletic group but instead have evolved in parallel. The tiny size of these spiders (carapace length ranges from 0.8 – 3.0 mm) precludes in vivo manipulations. Instead, I use micro-CT scanning techniques, histology, and high-speed videography to reverse engineer the trap-jaw mechanism. I compare and contrast the functional morphology of two different mecysmaucheniid lineages, both from New Zealand, that are each other's closest relative, with one lineage capable of ballistic, high-speed "jaw" movements and the other with slower movements. Based on differences in muscle morphology and anatomical shapes between the two sister-lineages, I develop a hypothesized mechanism for the trap-jaw strike. Finally, I test this mechanism by 3D printing a scaled-up model of different structures and use string and elastics to replicate "jaw" function, thereby demonstrating proof of mechanical concept. This research highlights the morphological steps that were taken to evolve a ballistic, complex, structural mechanism.

38-3 WOOD, LJ*; TOBALSKE, BW; ALTSHULER, DL; University of British Columbia, Vancouver, University of Montana, Missoula; *leo.w@zoology.ubc.ca*

A Specialized Muscular System Enables Highly Dynamic Wing Motions in Passerine Birds

Previous work indicates that strong coupling of elbow and wrist motion in birds results in an outsized influence of elbow angle on overall wing morphing. The muscular morphology of the avian wing that controls elbow flexion is highly unique. In addition to the biceps, there are two muscles unique to birds with attachment points and tendinous properties that are highly unusual relative to other vertebrates. This elbow flexion system has no parallel in other vertebrates, is highly diverse across avian species, and yet has not been studied in close detail. We sought to answer fundamental questions on what roles each muscle performs in flight, how the muscles in this system interact in different modes of flight, and what possible scaling relationships may bound and drive the morphological variation of this system. We collected *in vivo* electromyography and kinematics measurements on European Starlings in wind tunnel flights designed to elicit both gliding and level flapping behaviors. These investigations were coupled with isolated muscular studies to characterize the activation dynamics, force production, and torque production of the wing muscles of interest. We show that the three passerine elbow flexors exhibit a robust pattern of sequential activation that is closely rooted to their anatomical arrangement and muscular dynamics, and that the specific flexor muscles unique to birds utilize favorable lever arms to generate higher torques from comparatively lower muscle masses than traditional elbow flexors. This study provides a view of the interrelation between muscular morphology and coordination, and how a highly specialized avian muscular system is used to generate and control flight.

45-1 WOODLEY, SK*; MOORE, IT; Duquesne University, Virginia Tech; *woodleys@duq.edu*

Introduction to Celebrating the scientific contributions of Rosemary Knapp: hormones and alternative reproductive tactics

On February 3rd, 2019, Dr. Rosemary (Roe) Knapp, Professor at the University of Oklahoma, passed away after a long courageous battle with breast cancer. Roe was a dedicated member of SICB and DCE, serving as DCE program officer multiple times and was a longstanding active member since the early 1990s. She was a role model, mentor, colleague, and friend to many in the SICB community and beyond. Along with her bright smile and gracious attitude, she was highly regarded for her sharp intellect, her scientific rigor, and her high standards. Roe exemplified integrative and comparative biology through her published studies of ecology to neurobiology using many species, including caterpillars, mice, lizards, birds, and fish. Roe was best known for her studies of the behavioral neuroendocrinology of alternative reproductive tactics. Starting with aggression in male lizards with her PhD, she expanded into male parental care, aggression, and reproductive physiology in fish. Most recently, she was an integral member of the team that compiled HormoneBase, a valuable data repository that has allowed testing of broad hypotheses about patterns and functions of circulating steroid hormones in free-living vertebrates. Along with her scientific contributions, she was a caring mentor to students and colleagues alike and was the beloved graduate director at her home institution. Today, we celebrate and honor her influence on SICB and her impact on the field of hormones and alternative reproductive strategies with a series of talks by her friends and colleagues.

65-6 WOODLEY, SK*; CASCIO, M; KOLBER, BJ; MIHAILESCU, MR; TIDGEWELL, KJ; Duquesne University; *woodleys@duq.edu*

Community-engaged Learning in a Summer Undergraduate Research Program

Scientists are essential for communicating scientific concepts, the social relevancy of science, and the excitement of science and related fields to the public. However, scientists are rarely trained in how to effectively engage with the public. To address this gap, we incorporated community-engaged learning into the 10-week immersive summer undergraduate research program of Duquesne University. Students were funded by Biology NSF REU or NIH R25 grants. The summer research students developed and shared science activities with children at a summer day camp located in an underserved neighborhood in Pittsburgh. Undergraduate students worked in teams to develop science enrichment activities that they shared with 25 middle school-aged campers one morning each week for 4 weeks. The experience culminated in a visit by campers to Duquesne University where the undergraduate students described their background and research projects to the campers. An average of 12 hrs total was spent on community engagement activities. Assessment was via a retrospective post-test. The undergraduates reported statistically significant gains in communication, professional, and civic skills. At the same, Pittsburgh youth were exposed to hands-on science enrichment to increase their understanding and enthusiasm for biology. In sum, 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.

S1-12 WOODS, HA*; MORAN, AL; University of Montana, University of Hawai'i at Mānoa; *art.woods@mso.umt.edu*

Reconsidering the oxygen-temperature hypothesis of polar gigantism: successes, failures, and nuance

'Polar gigantism' describes a biogeographic pattern in which ectotherms in polar seas tend to have larger body sizes than do their warmer-water relatives. Although polar gigantism has been ascribed to a variety of mechanisms, one idea—the oxygen-temperature hypothesis—has received significant attention in the past twenty years. The idea is that low temperatures in polar seas depress metabolic demand for oxygen more than they depress supplies of oxygen to and within organisms. This shift, releases polar organisms from oxygen-based constraints on body size. In this talk, we review evidence for and against the hypothesis. Although some data suggest that larger-bodied taxa live closer to an oxygen limit, or that rising temperatures can challenge oxygen delivery systems, other data provide no support. We propose that these findings can be reconciled, in part, by recognizing that the oxygen-temperature hypothesis, in its simplest incarnation, focuses on *passive physical transport* of oxygen, which implicitly ignores other important processes, including ventilation of respiratory surfaces, internal transport of oxygen, and behavioral choices about positioning within environmental mosaics. Indeed, the oxygen-temperature hypothesis may apply most meaningfully to organisms that are sessile (e.g., nudibranch egg masses, sessile adults) or that have poorly developed physiological and behavioral systems (eggs and embryos). Finally, most tests of the oxygen-temperature hypothesis have involved short-term experiments. Although most complex organisms can mount effective responses to physiological challenges over such time periods, doing so may incur negative energetic consequences that become apparent only over much longer time scales. We therefore advocate a renewed focus on long-term studies of temperature-oxygen interactions.

68-1 WRIGHT, RM*; NUTTALL, M; DAVIES, SW; Smith College, Northampton MA, Flower Garden Banks National Marine Sanctuary, Galveston TX, Boston University, Boston MA; *rwright@smith.edu*

Gene Expression in Response to Experimental Low Dissolved Oxygen Supports the Hypothesis that Hypoxia Contributed to a Natural Coral Mortality Event

In July 2016, the East Bank of the Flower Garden Banks (FGB) National Marine Sanctuary experienced a localized mortality event (LME) of multiple invertebrate species that caused unprecedented reductions in coral cover for the reef. Abiotic data collected after the LME suggest that hypoxia driven by freshwater run-off and stratification contributed to the mortality. Yet, little is known about the molecular responses of corals to low oxygen. Gene expression samples from affected and unaffected coral colonies revealed physiological consequences of the event on the coral host and its algal symbiont from two congeneric coral species (*Orbicella franksi* and *Orbicella faveolata*) from both East (affected) and West (unaffected) Banks. Affected colonies differentially regulated genes involved in mitochondrial components and oxidative stress, suggesting a response to hypoxia. To test this hypothesis, we measured coral host and algal gene expression in response to experimentally induced low dissolved oxygen (control = 6.9 ± 0.08 mg/L, hypoxic = 0.083 ± 0.017 mg/L) in replicate fragments of three healthy *O. faveolata* colonies from the FGB. This controlled experiment also revealed differential regulation of mitochondrial components and oxidative stress response mechanisms. The delta ranks of enriched gene ontology terms were significantly positively correlated between the responses to the natural LME and in response to the controlled hypoxic challenge, providing further support that hypoxia contributed to the LME at FGB. These *in situ* and experimental data highlight the diagnostic power of an affordable sequencing methodology using ecological samples. Furthermore, our results shed light on the molecular responses of corals to hypoxia.

132-7 WU, C*; HOWLE, LE; MCGREGOR, AE; MCGREGOR, R; NOWACEK, DP; Marine Science and Conservation, Duke University, Mechanical Engineering and Materials Science, Duke University, School of Life Sciences, University of Glasgow, HiDef Aerial Surveying Ltd; *chen.yi.wu@duke.edu*

Computational Fluid Dynamics Analysis of Gliding North Atlantic Right Whale Models with Variable Body Shapes

The streamlined body shapes of cetaceans delay the separation of flow, create lower drag when they swim, and therefore decrease their locomotor cost in terms of energetics. However, previous studies show that body shape of the North Atlantic right whale (*Eubalaena glacialis*; hereafter right whale) changes with life stages, reproduction status, nutritive conditions, and the effects of entanglement. Accordingly, we aimed to investigate the changes in drag on right whales with variances in body shapes and estimate any associated kinematic costs. We hypothesized that emaciated right whales, which have a less-streamlined body configuration, suffer higher drag when swimming and consequently need longer time to replenish their energy reserves. This fact is likewise crucial for pregnant females because their energy budget for migrating to breeding grounds may increase due to having an enlarged girth for their abdomen. To obtain measurements of drag over right whales under various body conditions, we undertook computational fluid dynamics (CFD) simulations on several static right whale models reflecting different body fitness (e.g., normal condition, emaciation, and pregnancy, etc.) and measured multiple fluid dynamics parameters such as characteristics of boundary layer and hydrodynamic forces on the animals. Our results reveal that drag on right whales fluctuates across its body and varies between models of different body fitness, suggesting that the kinematic energy expenditure of right whales is indeed affected by its body shape.

115-4 WYETH, RC*; UCCIFERRI, C; YOUSSEF, K; STEVENS, H; St. Francis Xavier University; *rwyeth@stfx.ca*

Environment- Dependent Switching of Odour-Based Navigation Strategies by the Freshwater Gastropod, Lymnaea stagnalis

Many aquatic animals use olfactory-based navigation to move relative to prey and predators. Two common navigation strategies are used, depending on the flow in the animal's environment. To move towards or away from odour sources, either in no flow or laminar flow, chemotaxis can be used (moving up or down a chemical gradient), while in turbulent flow, odour-gated rheotaxis is used (moving up or downstream in the presence of an odour). Moreover, searching-for versus avoidance-of odour sources are distinct goals which need not require a simply inverted navigation strategy (there is only one odour source location, but many locations which could be sufficiently far from an odour source). Few studies have tackled this full complexity in one species. Navigation by the great pond snail, *Lymnaea stagnalis*, presents an interesting case in that they can experience both kinds of flow environments with both attractive (prey) and aversive (predator) odour sources. In a series of behavioural experiments, we are testing whether the snails can switch between chemotaxis and odour-gated rheotaxis, and how navigation differs relative to prey and predator odour sources. The results indicate that *L. stagnalis* can use either chemotaxis or odour-gated rheotaxis when moving towards at least some prey odour sources. Navigation relative to predator odour sources is categorically distinct, and seems to primarily involve upwards movement rather than horizontal movement away from the odour source. Other interesting results include diminished navigation success relative to plant prey versus greater success relative to protein-based odour sources and evidence that vision is integrated with odour-based navigation, at least in environments without flow.

S9-5 WYNEKEN, J*; SALMON, M; Florida Atlantic Univ; *jwyneken@fau.edu*

Science, Sea Turtles, and Links to Conservation Management

Fundamental and applied studies of protected species require governmental permissions. Permitted studies often have components directed to address conservation data gaps as defined in species recovery plans. Accurate guides for species identification and gross morphology are critical for managers so that subjects are correctly identified. Descriptive and experimental studies that distinguish normal vs. abnormal development, growth, or behavior are knowledge gaps commonly studied by biologists, but not regularly by managers. When declines occur, managers must understand if such changes result from natural or anthropogenic causes. Mistaken blame may result in ineffective management strategies. Several studies link fundamental science and management. Hatchling marine turtles migrate out to sea; how this migration is done differs among species. Some species swim briefly then allow currents to promote offshore displacement; others swim continuously for days. Differences also correlate with contrasts in hatchling size, shape and flipper morphology. Species also differ in visual perception manifested by contrasting structural organization of their retinae, sensitivity to light wavelengths, how visual information is processed during orientation, prey recognition, and other essential functions. Recognition of such differences has helped regulators better address problems associated with artificial lighting at nesting beaches and lights placed on fishing lines and nets that may attract turtles. Recent studies of nest environments improved understanding of the drivers of hatchling sex determination and thus contribute to population sex ratios. Collectively, the studies demonstrate how relationships in structure, function and behavior contribute fundamental knowledge as well as assist in development of better conservation/management strategies.

51-1 WYNNE, NE*; FRYZLEWICZ, LH; VINAUGER, C; Virginia Polytechnic Institute and State University, Blacksburg, VA; *nwynne@vt.edu*

Navigating Towards Defensive Hosts: Mosquito Visual Avoidance Behavior

In order to produce progeny female mosquitoes require proteins and nutrients found in our blood. This food is hidden under the skin of mobile and defensive vertebrate hosts. In response, mosquitoes have evolved the ability to navigate around hosts at close range while avoiding their defensive and antiparasitic behaviors. It is well known that invertebrates display escape behaviors in response to visual, predator-like, looming stimuli. In locusts and fruit flies a subset of neurons are specialized in the encoding of looming stimuli and descending pathways control these escape responses. However, in spite of great epidemiological relevance, very little is known about how mosquitoes evade their predators, as well as swatting from their hosts. As a first step towards bridging this knowledge gap, we combined behavioral and molecular approaches to analyze the responses of *Aedes aegypti* females to looming visual stimuli. In a first set of experiments we used an LED arena to introduce looming, predator-like stimuli to mosquitoes that were either landed, in free flight, or in tethered flight. Results from these experiments allowed us to characterize mosquitoes' escape responses and determine the angles and distances to the stimuli most likely to trigger an escape response under different behavioral contexts. Next, we relied on molecular and imaging approaches to investigate the underlying neural mechanisms supporting this behavior. The significance of these results will be discussed relative to the design of control tools.

132-6 XARGAY, E*; BARTON, K; GOUGH, W; ADAMS, D; FISH, F; ANTONIAK, G; SHORTER, KA; UMich, SU, CU, WCU, UM; *kshorter@umich.edu*

Inverse Dynamics Analysis of Dolphin Swimming

This work uses a physics-based model of a swimming bottlenose dolphin to investigate thrust production and propulsive efficiency. The model captures critical features such as body posture, fluke flexibility, and delayed fluke stalls, and integrates findings from previous research on small odontocetes, including body morphometry, fluke morphology and elasticity, gait and swimming stability. The modeling framework is based on a mixed Newtonian-Lagrangian formulation and brings together tools and concepts from multi-body dynamics, plate theory, hydroelasticity, and unsteady hydrodynamics. The head, torso, caudal peduncle, and pectoral fins are modeled as a set of interconnected rigid bodies subject to a prescribed kinematic gait profile relative to the torso. Gait kinematics are extracted from video data of bottlenose dolphins swimming over a range of speeds. The fluke, on the other hand, is modeled as a flexible plate, whose deformation evolves in response to hydrodynamic, elastic, and inertial forces acting on the fluke. Because hydrodynamic loading over the fluke is in turn affected by its deformation state, the model incorporates results from unsteady thin-airfoil theory and unsteady lifting-line theory to predict lift and drag distributions over the deforming body. An inverse dynamics analysis is used to estimate forces, moments, and power required to move elements of the model during the experimentally derived motion. We show that the swimming kinematics resulting from our model are in good agreement with kinematic data previously reported in the literature. We also present estimates of swimming energetics over a wide range of speeds, and compare these results with estimates obtained from previous work on cetacean swimming performance and oscillating hydrofoil propulsors. Finally, we discuss discrepancies between our findings and existing knowledge of the hydrodynamic performance of a swimming dolphin.

5-5 XU, NW*; DABIRI, JO; Stanford University, California Institute of Technology; *nicolexu@stanford.edu*

Metabolic costs of enhancing propulsion in live biohybrid robotic jellyfish

Robotic control of animal locomotion can potentially address questions about organismal biology and animal-fluid interactions, which are otherwise limited to observations of natural behavior. This work demonstrates a biohybrid robot that uses a low-power, wireless microelectronic system to induce forward swimming in live jellyfish, *Aurelia aurita*. When bell contractions are externally driven at a frequency range higher than observed in natural behavior, swimming speeds can be enhanced nearly threefold. This microelectronic system was also used to determine the metabolic response of the jellyfish over this optimal frequency range, which was only a twofold increase in cost of transport to the animal compared to unstimulated swimming. These experimental results are consistent with an adapted hydrodynamic model, developed to characterize enhanced propulsion and match more biologically relevant kinematic and body morphological parameters. Thus, jellyfish can sustain the associated higher metabolic costs of increased swimming speeds. This capability can possibly be leveraged in applications such as ocean monitoring and robotic sampling for ecological uses, and to enable more user-controlled studies of swimming organisms in lab and in-situ experiments.

87-4 XUAN, Q*; LI, C; Johns Hopkins University; *qxuan1@jhu.edu*

Template model reveals mechanism of wing and leg coordination during self-righting of a cockroach-inspired robot

Self-righting is a critical ability that terrestrial animals must have to survive. The discoid cockroach can push its wings against the ground to somersault and dynamically self-right. However, because this maneuver is strenuous, the animal often cannot build up sufficient kinetic energy to overcome the large potential energy barrier required to pitch the body. In this case, the animal often flails its legs, which adds kinetic energy to help overcome the barrier by body rolling. Our recent study using a cockroach-inspired robot showed that self-righting requires good coordination (good phases) between wing pushing and leg flailing. Here, we further understand the mechanism of phase dependence by developing a template model. Our planar template model rotates in the sagittal plane and has two massless wings and a flailing leg with mass at its end. Applying the similar geometry size, mass distribution, and actuation profile, the model also struggled to self-right and relied on a good coordination of body parts. We first validated the model against a multi-body dynamics simulation. Then, we used the template model to calculate mechanical energy injection by the wings and leg, mechanical energy dissipation due to collision and friction, and potential energy barrier. Our model revealed that, although phase affected energy injection and dissipation in complex ways, good phases resulted in mechanical energy accumulation that exceeded the potential energy barrier, whereas bad phases did not do so. Our study elucidated the mechanism of coordination between thrusting and perturbing appendages to cumulate energy to overcome the barrier during strenuous maneuvers such as self-righting.

S6-3 YACK, JE; Carleton University, Ottawa, Ontario, Canada; *jayneyack@cunet.carleton.ca*

What does a Butterfly Hear? Neurophysiological and Behavioural Responses to Predator Sounds

Butterflies are among the most extensively studied insects, and research on their behaviour has contributed to our understanding of animal territoriality, migration, conservation biology and climate change. A full appreciation of an animal's behaviour includes knowledge of its sensory ecology, and whilst visual, chemical, and tactile senses have been widely studied in butterflies, the auditory system is poorly understood. Recent work from my lab shows that many species of diurnally active butterflies possess tympanal ears on their forewings that are sensitive to low frequency sounds (best sensitivity ~1-6 kHz). Yet, a key question remains unanswered: What is the adaptive significance of their hearing? Most species are diurnally active and do not produce sounds, so bat detection or conspecific communication are unlikely. Birds are a primary predator of butterflies and we pose the hypothesis that butterflies (and other insects) use their ears as 'bird detectors'. We provide evidence that insectivorous birds produce broadband sounds as byproducts of flight that these sounds overlap with insect hearing. We show that butterfly ears respond neurophysiologically to predator sounds. Additionally, sounds of approaching predators evoke escape responses. Results to date support the hypothesis that the ears of butterflies, like those of many vertebrate prey such as some rabbits and lizards, function in predator risk assessment. We propose that the function of low-frequency hearing for predator risk assessment is underappreciated for both invertebrate and vertebrate prey, and warrants further investigation.

63-1 YANG, Y*; RICHARDS-ZAWACKI, CL; University of Pittsburgh, Pittsburgh, PA; *yusan.yang8@gmail.com*

Male Contest Limits Assortative Female Preference in a Color Polymorphic Poison Frog

Assortative mate preferences (i.e. the tendency to mate with phenotypically similar individuals) are widespread in animals and are hypothesized to facilitate speciation by limiting gene flow among diverging populations. However, male-male competition can either reinforce or suppress the expression of mate preferences. Therefore, it is essential to quantify the combined effect of both mate choice and intrasexual competition on mating patterns when studying the evolution of reproductive isolation. The strawberry poison frog (*Oophaga pumilio*) is a highly color polymorphic species at an early stage of divergence. Females generally prefer males of the same color morph, and this assortative pattern has been interpreted as a support for speciation via sexual selection. However, this inference does not account for male-male competition. We experimentally tested the relative importance and interaction of female preference and male-male competition. Females were housed with two size-matched, differently-colored males. We manipulated male territoriality so that the female's preferred phenotype is either the territory winner or the loser in the enclosure. These trios were kept together until one pair produced tadpoles, which we then genotyped to reveal paternity as direct evidence of reproductive success. Females mated assortatively when her preferred phenotype was the territory winner, but not when her preferred phenotype was the loser. This supports the hypothesis that male territorial status is a stronger driver of mating pattern than female color preference. Our results highlight the interaction between mate choice and intrasexual competition, and the importance to consider the combined effect of both selective forces in shaping phenotypic divergence and speciation.

134-6 YANG, DY*; GAMEL, K; FLAMMANG, B; SHORTER, KA; University of Michigan, Ann Arbor, MI, The University of Akron, Akron, OH, New Jersey Institute of Technology, Newark, NJ; *yangyayu@umich.edu*

Modeling and Experimental Evaluation of Traditional and Remora-inspired Suction Cups

Bio-logging tags enable behavioral studies of marine mammals and are often secured to the animals using suction cups to minimize impact. A secure attachment that does not interfere with locomotion or influence animal behavior is a key element of the tag system. Cup performance is dependent on the mechanics of the attachment surface. Marine mammal skin is made up of an anisotropic nonhomogeneous distribution of integrated tissue layers that possess variable viscoelastic properties which exhibit a nonlinear stress-strain relationship during loading and unloading processes. Current understanding of the biomechanical interface between the skin and cup is limited, and the experimental evaluation of suction cup performance on soft tissue is lacking. In this study, a specifically designed test setup that incorporates a uniaxial tension test machine, a pressure transducer and a camera is used to record the force, elongation, pressure differential, and deformation of a suction cup on a soft surface during controlled loading. Data from the experiment are used to create a simplified model of the coupled system that is used to examine design parameters and performance trade-offs between cup designs. These design tools are then used to refine and experimentally evaluate a remora-inspired suction cup design. These results provide an improved understanding of the coupled cup/skin system, as well as facilitating bio-inspired suction cup design.

102-1 YANG, ZY; EASY, RH*; AVERY, TA; Acadia University; *jacksonyang@acadiau.ca*

Identification and quantification of Atlantic Salmon Salmo salar, Arctic char Salvelinus alpinus, Cod Gadus morhua, and Capelin Mallotus villosus in Striped Bass diets in Labrador

In 2017, Striped Bass were found for the first time along the coast of Labrador, Canada. The presence of Striped Bass in Labrador can potentially affect local fisheries because it is a piscivorous predatory fish. Striped Bass may feed on commercially fished and 'at-risk' species such as Atlantic Salmon, *Salmo salar*, Arctic char, *Salvelinus alpinus*, Cod, *Gadus morhua*, and Capelin, *Mallotus villosus*. Our objective was to use traditional and molecular tools to identify and quantify Striped Bass diets. Three methods of diet analysis were chosen for this study: traditional analysis (TA) through dissecting stomachs and counting identifiable prey using morphological methods or examination of otoliths, molecular analysis (MA) whereby gastric DNA was used to identify prey to species, and stable isotope analysis (SIA), which was used primarily to identify diet trophic level. In general, TA identifies prey within a few days of being eaten, whereas MA widens this window to perhaps a week. SIA provides a diet indicator on a local trophic level perhaps reflecting several weeks. Stripe Bass carcasses were collected from recreational anglers, and from commercial fisher bycatch. The current focus is to develop the MA method. MA uses quantitative PCR to identify target species and provide a proportion of different prey species in the overall diet. The method relies on species-specific primers targeting conserved genes in suspected prey. Using various diet analysis methods may provide a more reliable and robust picture of these large predators.

6-4 YANG, Y*; PAN, Y; UYANIK, I; COWAN, NJ; Johns Hopkins University; *yyang138@jhu.edu*
The Selection of Stimuli Affects Non-parametric System Identification for Refuge Tracking Behavior in Eigenmannia virescens
Mathematical models are widely used to study animal behaviors. But for high-level tasks like sensorimotor processing, dynamics cannot be easily predicted by simple physical models. In these cases, data-driven system identification techniques are essential. This study focuses on system identification of refuge tracking responses in weakly electric glass knifefish, *Eigenmannia virescens*. During refuge tracking, fish swim forward and backward to track the movement of an actuated refuge. In these experiments, we command the refuge to follow one of two predefined input signals tuned to have similar overall signal power: (1) a sum of sinusoids comprising 13 single sine components with frequency of 0.1 Hz-2.05 Hz and (2) noise, filtered to 0 Hz-2.5 Hz. We use real time image processing software to record digitized refuge and fish trajectories. Given these input-output data, we use non-parametric system identification techniques to estimate the Frequency Response Function (FRF) of refuge tracking responses. To investigate how input signal selection affects FRF estimation, we performed an Empirical Transfer Function Estimate (ETFE) of the FRF. Preliminary results for N=2 fish suggest that ETFE performs reasonably well for the sum-of-sines stimulus, likely due to the high signal-to-noise ratio at a small number of frequencies, but produces erratic estimates for the pseudorandom input. Fortunately, FRF estimation for the noise stimulus is dramatically improved by introducing overlapped hamming windows to smooth time domain data. We find the improved noise input FRF estimation is similar to the result of deterministic input case, a critical validation that refuge tracking dynamics are approximately linear in this regime.

34-2 YAP-CHIONGCO, MK*; VARNEY, RM; KOCOT , KM; University of Alabama, University of Alabama , University of Alabama and Alabama Museum of Natural History ; *mkyapchiongco@crimson.ua.edu*
What the Shell-less Aplacophorans Can Tell us About Molluscan Biomineralization
The great diversity and success of molluscs can partially be attributed to their ability to secrete diverse biomineralized structures. Aplacophora is a group of vermiform molluscs that lack a shell but are instead covered with calcareous scales or spines called sclerites. Aplacophoran sclerites are composed of calcium carbonite polymorphs like conchiferan (e.g., gastropod and bivalve) shells, but homology of these different biomineralized structures has not been tested. Transcriptomic and proteomic approaches have provided insight into the genes and proteins responsible for patterning the shells of conchiferan molluscs. These studies have shown the expression of both highly conserved and lineage-specific genes in mantle transcriptomes of distantly related mollusc species. Investigation into the biomineralization toolkit of aplacophoran is needed. Here, we present an ongoing project aimed at addressing these questions focusing on draft assemblies of the solenogaster aplacophorans *Neomenia megatrapezata* and *Epimenia babai*. Our sequencing strategy combined Illumina HiSeq X paired-end reads and multiple flow cells of Oxford Nanopore GridION long reads to produce hybrid assemblies using MaSuRCA. Assemblies will be scaffolded with optical mapping and subsequently annotated to identify genes involved in biomineralization. Proteomics will be used to confirm protein products within the sclerites and expression patterns will be examined in larvae using *in situ* hybridization. This work will shed light on the formation of sclerites, their homology to conchiferan shells, and the biomineralization toolkit of the last common ancestor of Mollusca.

39-5 YARGER, AM*; SMITH, AJ; RAZMI, AN; FOX, JL; Case Western Reserve University, Cleveland, OH; *amy9@case.edu*
Haltere synchrony in flies
The ability of dipteran insects (flies) to perform complex acrobatic maneuvers while maintaining stability in flight is due in part to specialized sensory organs called halteres. Halteres are modified hind-wings that oscillate in antiphase with the fore-wings during flight and detect inertial forces produced by body rotations (Nalbach 1993). The halteres are coupled with the wings during flight through mechanical linkages in the thorax (Sane et al. 2015). How is the synchronization between the two halteres maintained and are they synchronized during other behaviors? Is the connection between the left and right haltere purely mechanical or is there a sensory component to their synchronization as well? Here we show that the halteres are not synchronized during walking and flight initiation behaviors. Halteres are only reliably synchronized when flies flap their wings at high frequencies with the wings intact. Flies with clipped wings flapping at high frequencies or intact wings that are either stationary or flapping at low frequency do not oscillate their halteres in synchrony. This suggests that sensory input from the wings may contribute to haltere-haltere synchronization.

20-6 YEGHISSIAN, TG*; DARNELL, MZ; University of Southern Mississippi; *talene.yeghissian@usm.edu*
Impact of Thermal-Hydric Stress on Surface Activity and Waving Behavior of Fiddler Crabs
Social and environmental factors influence the behavioral decisions of all animals. Behavioral choices require time and energy investment, and tradeoffs occur when critical behaviors must be performed in specific habitats. Ectotherms in thermally stressful environments reduce stress by altering microhabitat use, yet behavioral thermoregulation using shade or burrows can lead to missed opportunities if functions like reproduction must occur in stressful areas. Fiddler crabs mate in high intertidal areas, where males perform a claw-waving display. Courting behavior is limited by heat and desiccation stress, which is ameliorated by retreat into cool moist burrows. Yet this burrow retreat requires a cessation of mating behavior and thus a potential fitness cost. We examined impacts of thermal-hydric stress on surface activity and waving behavior in the fiddler crab *Uca pugilator*, an abundant sandy-shoreline species extending from Massachusetts to the Bahamas. The present study focuses on three sites along the species latitudinal-thermal range: Panacea, FL (30.0159°N), Beaufort, NC (34.7115°N), and Stony Brook, NY (40.9357°N), allowing for the examination of the trade-off between thermal-hydric stress and mating success under different thermal regimes. Operative body temperatures were quantified using physical models and compared to preferred temperatures to assess thermal habitat quality at each site. Simultaneously, body temperatures and hydration states of surface-active males in the high-intertidal breeding area were measured. In order to evaluate the impact of thermal-hydric stress on surface activity and waving behavior, video footage was used to quantify activity budgets (including time on the surface and time in the burrow) across a range of thermal conditions.

16-2 YEN, J*; LI, W; Georgia Tech, School of Biol.Sciences, Atlanta, GA, Georgia Tech, School of Industrial Design, Atlanta, GA; *jeannette.yen@biosci.gatech.edu*

Bio Inspired Design: translating biology to engineering and design

Biologically inspired design takes superlatives of Nature and translates into designs and engineering processes. Bio inspired design avoids design fixation by starting off with multiple sources of bio inspiration. In our class, each student searches for phylogenetically related, convergently evolved and champion adaptors for a function of interest, e.g. capability to stick and detach or be seen or unseen. Often, design rules in nature are found using phylogenetic and convergent evolutionary analyses to find common patterns leading to similar functions for deep bio inspired designs. Once key articles are found for each organism, the student performs a functional decomposition to define how the behavior of interest occurs. Then - as a team of 5 interdisciplinary majors, they have a total of at least 25 sources of bio inspiration. To organize the information into a useful format, a species x function matrix is constructed where each function is linked to the functional decomposition that details how that function is achieved. To invent a new bio inspired design requires the students to find key patterns and abstract that to an application. Evaluation of designs based on creativity and analogical goodness-of-fit will be examined. Some tricks of the trade that promoted interdisciplinary learning and engagement in education include: cognitive dissonance, functional matrices, pattern abstraction, identification of key levers. Consideration of performance and scalability are applied to test credibility vs technology readiness level [TRL] of the final designs. Teaching this course gives value to Nature through this education and research avenue.

139-7 YOUNG, JW*; WILSON, A; PHELP, T; DUNHAM, N; NEOMED, Cleveland Metroparks Zoo; *jwyoung@neomed.edu*

Effects of support diameter on vertical leaping performance in tree squirrels (Sciurus carolinensis)

Leaping is common in small-bodied arboreal tetrapods, where acrobatic locomotion is often required to move among the three-dimensional substrates of the canopy. However, the narrow diameters of arboreal substrates may constrain leaping performance by comprising mechanical work production during the push-off phase of the leap - i.e., the period prior to aerial take-off when the animal is accelerating the center of mass (CoM) by pushing against the substrate. We used high-speed video and force platforms to investigate the mechanics of three squirrels (*Sciurus carolinensis*) leaping vertically from flat substrates and poles 9.1, 4.9, and 3.5cm in diameter. Contrary to our hypothesis, leaping performance was not compromised by substrate diameter. Projected leap height (calculated using ballistic equations) did not significantly differ among substrates ($p=0.18$). However, squirrels used different mechanical strategies to produce the mechanical work required to accelerate the CoM on flat and cylindrical substrates. For a given level of performance (i.e., terminal CoM velocity at the end of push-off), squirrels emphasized greater force production on flat substrates versus increased CoM displacement on cylindrical substrates (all $p \leq 0.001$). Our results have implications for understanding leaping adaptations in arboreal animals, suggesting that adaptations to maximize CoM displacement (e.g., greater hindlimb lengths) maybe be more critical for increasing performance than adaptations to maximize force production (e.g., increased hindlimb muscle mass). Future work should investigate how other aspects of arboreal substrate variation, such as angular orientation and compliance, affect mechanical work production during leaping. Supported by NSF BCS-1126790 and NEOMED

22-2 YOUNG, R/L*; HOFMANN, H/A; University of Texas at Austin; *youngrl@utexas.edu*

Leveraging Network Analysis to Study the Evolution of Sociality in Vertebrates

Recent comparative studies of complex behavioral phenotypes find evidence that homoplasy, or the evolution of similar phenotypes in unrelated species, is often associated with similar transcriptomic patterns even across vast phylogenetic distances. However, comparing complex phenotypes fairly across distantly related species requires the development of rigorous, quantitative metrics, which have been elusive for the study of social evolution because behavioral phenotypes represent emergent properties of the organism and integrate multiple organismal systems (e.g., sensory and motor systems). Here, we introduce a quantitative approach to characterize diverse forms of sociality and compare independent evolutionary transitions to social dominance. Social dominance systems – where some individuals are dominant over subordinate group members, control access to resources, and attain more reproductive opportunities – have evolved repeatedly across vertebrates and beyond. In such groups, individuals may assume a specific set of behavioral characteristics – such as social polymorphisms or reproductive tactics (or "types") – because of genotype, developmental events, individual condition, and/or social or ecological opportunity. Using a quantitative social network modeling approach, we compare attributes of social status and network position across types in independent evolutionary transitions to social dominance systems. We ask how components of social dominance vary, whether similar social and reproductive types emerge, and how types vary in social status attributes and network properties across vertebrates. Finally, we discuss the implication of our approach for identifying the evolutionary origins and underlying neuromolecular mechanisms of social dominance systems.

S1-9 YOUNG, JN*; DAWSON, HM; RUNDELL, SM; University of Washington; *youngjn@uw.edu*

Responses of Antarctic Microalgae to Seasonal Shifts in Temperature and Salinity

Microalgae in polar oceans possess a number of physiological adaptations that allow them to thrive under extreme conditions. These include adaptations to low light, cold temperatures and fluctuating salinity. Here, I will show results from two experiments testing how Antarctic microalgae respond to seasonal shifts in temperature and salinity. In the first experiment we use metabolomics to explore how axenic laboratory cultures of the sea-ice diatom, *Nitzschia lecointei*, respond to a matrix of temperatures (-1C, +4C) and salinities (32, 41). While there was only a small effect on overall growth rates and photophysiology, we observed large shifts in the metabolome, particularly in the regulation of compatible solutes. For the second experiment, natural phytoplankton communities from the Western Antarctica Peninsula are incubated at three different conditions: sea ice (-3C, salinity 50), seawater (0C, salinity 32) and melt (+3C, salinity 20). Here, we saw clear differences in net community production and composition over a 10 day period. We will discuss how seasonal changes in temperature and salinity impacts cellular composition and health and how responses at a cellular level could have far reaching impacts on larger scale polar ecology and biogeochemistry.

1-3 YOUNG, BA; Kirksville College of Osteopathic Medicine; *byoung@atsu.edu*

CSF flow dynamics in Alligator mississippiensis: The role of the myodural bridge

Despite its clear clinical significance, the underlying flow dynamics of the CSF remain poorly understood. The study was intended to quantify some of the physiological features that contribute propulsive force to the CSF. Juvenile American alligators (*Alligator mississippiensis*) with a body length of approximately 180 cm were physically restrained on an inversion table. Using a cuffed tracheal tube the animal was connected to a mechanical ventilator and anesthetized with Isoflurane. Fluid pressure catheters were surgically implanted into the spinal and cranial subdural spaces. Surface EKG electrodes were placed on the ventral scalation on either side of the heart. The suboccipital muscles of the myodural bridge were surgically exposed on one side, implanted with bipolar EMG electrodes, and activated with a stimulating probe. In the first round of the experiment CSF pressure was recorded simultaneously with heart rate, ventilatory airflow, myodural bridge contraction, while the animal was exposed to varying gravitational gradients. FFT analysis of the pressure recordings was used to examine the relative contribution of the ventilatory movements and arterial pulsations. During the second round of the experiment ultrasonography was used to test for displacement of the dural sheath during contraction of the myodural bridge. During the third round of the experiment, artificial microspheres were introduced into the CSF and their pattern of movement studied using laser Doppler ultrasonography. All three rounds of the experiment provided support for the hypothesis that the myodural bridge functions as a CSF pump.

123-1 ZACHOS, LG; University of Mississippi; *lgzachos@olemiss.edu*

Matrix Models for Logistic Plate Growth in Sea Urchins

The coronal skeletons of modern sea urchins comprise 20 columns of plates, of two basic types (ambulacral and interambulacral), in five paired sets. Following an initial plate configuration derived from the rudiment, plates are added to each column over the lifetime of the animal. The growth of individual plates of a sea urchin can be accurately modeled by logistic functions. The addition and growth of plates in a single column can be envisioned as a stage-structured density-dependent Markov chain, where stages represent plate cohorts. The parameters of the Markov model, represented on a life cycle graph, can be used to define a tridiagonal transition matrix. Inclusion of density-dependent factors results in a model of logistic growth. The model has the general form $\boldsymbol{X}(t+1) = \boldsymbol{QAX}(t)$ where $\boldsymbol{X}(t)$ is an n-dimensional size vector at age t, $\boldsymbol{A}$ is an n×n tridiagonal transition matrix, and $\boldsymbol{Q}$ is an n×n density-dependent damping matrix. The model thus assumes that the growth of a plate at a given stage is dependent on the state of the previous plate stage and some function of plate density. The transition matrix and damping coefficients are unknown *a priori* and require solution of an inverse model using a Monte Carlo approach. The inverse models are derived from estimated plate growth series (beginning with the classic Deutler model of *Echinus esculentus*) and adult plate size distributions measured from 3D scans of species representative of major clades of regular sea urchins. The Markov model is shown to generate the stable plate size distributions of these different clades of sea urchins. This offers a new approach to quantifying the growth of these organisms.

110-2 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*

Zoo Versus Wild: Trabecular Bone Architecture in Captive and Wild Xenarthra

Captive (zoo) specimens in natural history collections allow researchers to inspect the morphologies of rare or CITES-listed taxa, but the lifestyles, diets, and lifespans of captive animals differ from those of their wild counterparts. To quantify these differences, we compared trabecular bone architecture (TBA) of dorsal vertebrae in captive and wild specimens of xenarthran mammals (anteaters, armadillos, and sloths). Because TBA develops following in-vivo bone force regimes, it reflects ecology and behavior, but this also 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 15 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 (TbN), mean trabecular thickness (TbTh), degree of anisotropy, and trabecular orientation. We found that wild specimens generally have a greater BVF, TbN, and TbTh than captive specimens, but that these metrics differ by species, vertebral position, ecology, and pathology. Wild specimens of *Dasypus* have greater BVF, TbN, and TbTh than captive specimens in the three most posterior lumbar vertebrae, but have much closer metrics in the anterior three vertebrae. In *Choloepus*, BVF, TbN, and TbTn are greater in wild specimens in the anterior vertebrae and more similar in the posterior vertebrae. Arthritis in captive *Tamandua* increased BVF and TbTh, whereas wild specimens had greater TbN. Our results add to overall understanding of variation in mammalian vertebral trabecular bone, and suggest caution when including captive specimens in research on the relationship between TBA and ecology.

112-7 ZAHOR, DL*; GLYNN, KJ; CHIPARUS, S; CORNELIUS, JM; Eastern Michigan University, Oregon State University; *dzahor@emich.edu*

Bioaccumulation of lead (Pb) in songbirds following the Flint, Michigan drinking water crisis

Pollutants, including heavy metals, can interact with animal physiologies in ways that negatively impact fitness. Human activities emit unnatural levels of metal pollutants such as lead into the environment in various ways, including historical use of leaded gasoline, current vehicular emissions, industrial production and other types of catastrophes. Lead is a neurotoxin that is highly persistent in the environment and is thus of particular concern for humans as well as wildlife. From 2014 to 2017 the Flint, Michigan drinking water crisis caused lead to leach from pipelines into the drinking water in some neighborhoods. While human residents were belatedly alerted to avoid ingestion of lead-contaminated water, there was not a similar caution taken when watering lawns or otherwise allowing the drinking water to exit Flint homes and enter the environment. Although water levels are now reduced, lead is highly persistent and tends to remain in the upper layers of soil where it is bioavailable to wildlife. Foraging differences, however, may drive patterns of lead exposure across species and may influence bioaccumulation despite the fact that species may forage in the same site. Omnivorous songbirds forage for invertebrates by digging into the soil, potentially exposing them to soil lead, while granivores forage at the tops of plants for seeds or in feeders. This research explores bird blood lead levels of both omnivores and granivores in Flint, MI in watered and unwatered sites in comparison to reference sites within southeast MI. This study investigates the impact of the Flint, MI water crisis on lead exposure of urban songbirds, as well as how diet impacts lead accumulation.

58-3 ZAKAS, C*; ROCKMAN, M; North Carolina State University, New York University; *czakas@ncsu.edu*

How Maternal Genetic Effects Shape Developmental Evolution

Phenotypic evolution in animals is constrained by the mechanics of early development. Large-scale evolutionary changes are initially shaped by developmental program, where simple trade-offs can ultimately result in a vast spectrum of physiological, morphological, and ecological differences. Because early development is strongly influenced by maternal effects, we focus on finding the genetic contribution of maternal background to developmental phenotypes. The polychaete *Streblospio benedicti* provides a unique opportunity to address this issue because it has two types of mothers who produce distinct offspring that differ in egg size, early development, and larval morphology. It is an ideal genetic model for understanding how transitions in developmental program evolve. Using crosses between these types, we reveal the distribution of genetic factors affecting a suite of developmental phenotypes. Our cross design further isolates the role of maternal genetic effects on development. By identifying the loci responsible for early developmental phenotypes, we begin to uncover how major transitions in development evolve.

27-6 ZANG, H*; NAGAYASU, N; Lyon College, University of Arkansas ; *hannah.zang@lyon.edu*

The evolution of novel neuropeptides in Cnidaria: investigating the function of a lineage-specific neuropeptide RPamide during sea anemone development

Understanding how new neuropeptides become functionally integrated into the pre-existing nervous system during evolution is important for understanding the mechanism by which neural function evolves. In Cnidaria, novel neuropeptides known as RPamides likely emerged in the sea anemone lineage, but little is known about their function. To bridge this fundamental knowledge gap, we examine the expression pattern of RPamides during development of the sea anemone *Nematostella vectensis*. We show that RPamide precursor transcripts first occur during gastrulation in scattered epithelial cells in the aboral ectoderm. These RPamide-positive epithelial cells then extend basal neuronal processes toward the aboral pole, forming an aboral sensory nerve net of the planula larva. During planula development, several RPamide-positive sensory cells become part of the aboral apical organ, and a subset of endodermal sensory cells begin to express RPamides. During metamorphosis into a polyp, RPamide-positive sensory cells in the aboral ectoderm disappear via apoptosis, and RPamide-positive ectodermal sensory cells develop in growing oral tentacles. These expression data strongly suggest a role of RPamide in sea anemone development and/or larval behavior. Interestingly, the developmental expression pattern of RPamide differs from those of RFamide and GLWamide - ancient families of neuropeptides thought to have been present in the last common ancestor of Cnidaria and Bilateria – indicative of distinct functions. Thus, during cnidarian evolution, RPamides may have acquired new function that pre-existing neuropeptides did not have; alternatively, RPamides may have inherited old function that pre-existing neuropeptides subsequently lost. We are currently taking a CRISPR-Cas9-mediated gene knockout approach to directly test RPamide function during *N. vectensis* development.

S8-9 ZAMORE, SA*; ARAUJO, N; SOCHA, JJ; University of Colorado Boulder, Virginia Tech; *sharri.zamore@colorado.edu*

Visual behavior in flying snakes: measurement and exploration with virtual reality

Flying snakes (genus *Chrysopelea*) are highly visual animals that climb, jump, and glide while navigating through tropical rainforests. These arboreal behaviors likely produce different visual problems than terrestrial locomotion. For example, gliding requires visual assessment to determine position, distance, and speed. To wit, flying snakes have large eyes, and perform visually-guided behaviors, such as tracking birds that are flying overhead. While some visual behaviors in arboreal snakes are well-described, their visual capabilities and its role in decision-making remains largely unknown. The visually sensitive flying snake is an ideal model to explore this relationship.

The use of closed-loop stimuli—stimuli that is modified based on behavioral output—has proven to be a useful tool for exploring visually-guided behaviors. To test the functionality of closed-loop systems on visually-guided limbless locomotion, we developed an Immersive Virtual Visual Arena (IVVA). The arena is a 3-foot cube with translucent walls onto which images were back-projected from LCD projectors. The projected visual stimuli were created with Unity 3D game development software. We tracked a marker on the head of the snakes using a Leap Motion Sensor, d its position using OpenCV, and updated the stimuli in Unity. The snakes were placed on an air table inside the cube, which inhibited translative locomotion, while allowing them to freely move.

Preliminary results show that behavioral responses in the virtual arena approximate those seen in an "analog" setup. This talk will 1) review previous visual research on the flying snake (*Chrysopelea paradisi*) that contributed to the specifications of the IVVA, and 2) discuss the design and development of an affordable IVVA, and its performance when exploring visually guided behaviors.

10-3 ZAPFE, KL *; LAROUCHE, O; PRICE, SA; Clemson University; *kzapfe@g.clemson.edu*

Macroevolutionary Relationships Between High Contrast Patterns and Body Shape in Teleost Fishes

Visually striking animals are found across the Tree of Life, but we are still untangling the story behind bold color pattern displays. Color patterns can help animals achieve crypsis or communicate with conspecifics and other species. Bold patterns such as stripes (horizontal linear patterns), bars (vertical linear patterns) and contrasting spots can also help animals avoid recognition by visually disrupting a recognizable body outline. Further, some disruptive patterns are hypothesized to combine with movement to create erroneous speed and direction signals (motion dazzle), or redirect attacks towards the anterior (motion redirection). Such misleading signals are hypothesized to help thwart predation. While studies continue to resolve the proximate drivers of color pattern evolution, the influence that they have on broad taxonomic and time scales remain much less resolved. We employ phylogenetic comparative methods to explore the evolutionary history of color pattern traits across a diverse radiation of vertebrates: teleost fishes. Additionally, we assess the potential coevolutionary relationship between bar and stripe patterns and body streamlining in fishes. Consistent with early observational work on fish depth and stripe orientation on the body, our quantitative macroevolutionary analysis reveal that fishes with different orientations of linear patterning (i.e. barring, striping) possess differing body shapes. Fishes with bar patterns have less streamlined body shapes while striped fishes have more streamlined shapes. These results suggest that predation predation pressure may drive coevolutionary dynamics between color pattern traits and morphology over macroevolutionary scales.

118-3 ZELDITCH, ML*; SWIDERSKI, DL; University of Michigan, Ann Arbor; *zelditch@umich.edu*
An Incisor Runs Through It I. Variational modularity of the squirrel mandible
Modularity enables complex morphologies to evolve, by coordinating variation of functionally coupled traits within modules, which, being quasi-autonomous, can vary independently of other modules under stabilizing selection. Consequently, modular complexes can be optimized without interfering with adaptations of other modules. The rodent mandible has long served as a classic example of modularity, but the hypothesis of modularity for the mandible is of two "functional modules": the tooth-bearing front and the muscle-bearing back. That is difficult to reconcile with the idea that the mammalian mandible can be modeled as a beam because a beam is not divisible into two functional complexes along its length. It is even more difficult to reconcile with the rodent mandible because the incisor runs through it, well past the boundary between the modules, and the masseteric muscle overlaps the border in the other direction. The question is: why would the front/back model fit so well, if it does? We find, using the Covariance Ratio, that it does fit well in eight species of squirrels from both tree- and ground-squirrel lineages. However, if we extend the beam of the horizontal ramus posteriorly through the back (to the bases of the posterior processes), and analyze correlations between the shapes of those regions, we find a high correlation between that posterior segment and the anterior (diastema) and/or middle (molar) in most of the species we analyzed. The exceptions are species that have high correlations between those anterior regions and at least one posterior process. On average, regions of the front may be more highly integrated than they are with the back but in no case are front and back even quasi-autonomous.

56-2 ZHANG, Y*; BARNES, SJ; KENKEL, CD; University of Southern California, Los Angeles, CA; *yingqizh@usc.edu*
Familial effects on the thermal tolerance of the brooding coral Porites astreoides during early life stages
The capacity to adapt and/or acclimatize to local environmental conditions has been demonstrated in a wide array of marine organisms to date. Understanding how these adaptive and acclimatory mechanisms affect species survival and fitness at different life stages is especially relevant in the context of climate change, as certain life stages may be more vulnerable to environmental disturbances than others. Reef-building corals exhibit the classic marine life-history dichotomy of sessile adult populations linked by a dispersive planktonic larval stage. We found that the majority of the variation in symbiont density, chlorophyll a and protein content, and survival under acute thermal stress in *Porites astreoides* larvae was driven by larval family rather than day of release or reef origin. To investigate whether this family-level variation persists into recruit and adult life stages, we collected adult *P. astreoides* from two reef zones in the lower Florida Keys in April 2019 and obtained both larvae as well as subsequent juvenile recruits from 5 colonies per site. After being exposed to a 32 °C sublethal temperature treatment, *P. astreoides* adults, larvae, and recruits were sampled to quantify symbiont density, chlorophyll a content, and total carbohydrate content. Additionally, photographs were taken to assess the growth rate of recruits and bleaching status of both recruits and adults throughout the heat stress experiment. This study expands on our understanding of familial effects on thermal performance by linking traits across multiple life stages, which has significant implications for population dynamics and overall community structure in a rapidly changing ocean.

106-7 ZHANG, Y*; WONG, HS; University of Memphis, Buck Institute for Research on Aging ; *yzhang24@memphis.edu*
Are mitochondria the major contributor of reactive oxygen species production? No.
Oxidative stress has been proposed as a mediator underlying different life-history trade-offs. Evolutionary physiologists often assume mitochondria as the center of release and regulation of reactive oxygen species (ROS) levels. Unfortunately, evidences for such an assumption were limited since ROS production levels from different cellular compartments in intact cells were difficult to quantify. Previous studies relied heavily on intracellular fluorescent probes, but such probes are only useful for qualitative rather than quantification of ROS. In the present study, we employed a newly developed method to accurately quantify ROS production from different cellular compartments. We surveyed a large variety of cell types including primary cells from different tissues of various species. Moreover, we also measured changes in ROS profile during tunicamycin induced ER stress as an example for a stress model. Overall, the significance of mitochondria ROS production varies between cell types, with their contribution to total cellular ROS production being less than 50% in majority, but H9c2 cardiomyocytes, of cell types. On the other hand, other cellular compartments such as NADPH oxidases contributed a major portion of ROS production in some cell types under unstressed conditions. These data show mitochondria are not the major site of ROS production in all cell types. As a result, when studying life-history trade-offs, we must be cautious and should not always assume ROS production comes from mitochondria.

107-3 ZHAO, X*; MILLION, W; KENKEL, C; University of Southern California, Department of Biological Sciences, Los Angeles, CA; *xuelinzh@usc.edu*
Gene expression noise its role in coral responses to environmental variation
Analysis of differentially expressed genes under different stressors or development stages is a common method for investigating physiological response mechanisms of organisms and their tissues. But notably, gene expression in individual cells is often noisy and dynamic and the expression patterns of genetically identical cells under the same environment can be widely different. This gene expression noise has been shown to significantly impact the fitness of unicellular organisms. However, the influence of noise on the relationship between genotype and phenotype in multicellular organisms remains unclear. Reef-building corals are a promising system in which to evaluate the ecological and evolutionary significance of gene expression noise as asexual clonal reproduction is a common life-history strategy. We analysed gene expression variability between replicate clonal fragments (~ramets) of ten Acropora cervicornis genotypes growing in a common garden nursery. Hundreds of genes exhibiting high inter-ramet variability, or noise, were identified. Different genotypes varied in the top ontology enrichments identified among noisy genes, but genes related to structural organization were enriched in all genotypes. Almost half of genotypes also exhibited enrichment of genes related to toxin activity and energy metabolism in noisy genes. Patterns of expression noise will be correlated with both global expression and other physiological trait responses of ramets following one year of transplantation to novel reef environments in the Lower Florida Keys to quantify the role of expression noise in acclimatization to environmental variation.

76-2 ZHONG, B*; SCHIEBEL, P; OZKAN-AYDIN, Y; BROWN, M; CARRUTHERS, A; RIESER, J; SPONBERG, S; GOLDMAN, D; Goergia Tech; *baxichong8@gmail.com*

Coordination of body undulation and leg wave during centipede locomotion, in a geometric perspective

Epimorphic centipedes running at high speed display a characteristic body undulation. Elucidating the interplay between body and limb waves and the resulting running performance is difficult because of the many degrees of freedom in the flexible body and numerous limbs. We characterized the body undulation and the limb stepping wave using amplitude and wavenumber, and captured the coordination by the relative phasing between the two waves. We used geometric mechanics (e.g. Hatton et al., PRL, 2013), in which inertial effects were assumed negligible, to model and predict the locomotion performance of a centipede with 19 leg pairs and body joints. Our theory predicted that the body-lengths traveled per cycle (BLC) was maximized when the body undulation (with 1.6 waves, maximum body curvature = 0.42 BL^(-1)) had a phase 2.51 rad ahead of the leg wave (with 2 waves, maximum leg joint angle 0.65 rad). At this phase offset, the theoretical prediction of centipede speed was 0.40 BLC, compared to 0.25 BLC with no body undulation and 0.10 BLC with worst body undulation. Using high-speed video, we captured the motion of five trials of centipede (*Scolopendra polymorpha* , 19 leg pairs) running on a treadmill and tracked the position of each leg and body. The centipedes ran at 0.41±0.05 BLC with a leg-body phase offset of 2.51±0.71 rad, in good agreement with our best-performing theoretical prediction. The good agreement indicated that our geometric approach can capture the kinematics of centipede locomotion without including inertial effects. Further, our results revealed that body undulations enhanced running performance, but only if the body and limbs were properly coordinated.

120-3 ZHU, JJ*; WAINWRIGHT, DK; LAUDER, GV; BART-SMITH, H; University of Virginia, Charlottesville, VA, Harvard University, Cambridge, MA; *jz8n@virginia.edu*

Tuna robotics: design and control of an autonomous underwater vehicle inspired by tuna

Design of bio-inspired autonomous underwater vehicles (AUVs) is of scientific and technological importance. Most current autonomous "fish-like" robots usually suffer from slow speed, energy inefficiency, low maneuverability, and high cost. Our previous thunniform robotic platform has successfully addressed these challenges by implementing a high efficient propulsion system. In this study, we further developed the Tunabot into an autonomous version of the platform. The autonomous Tunabot is powered by a 42 Wh battery pack and controlled with an ARM Cortex M3 microcontroller. It measures 387.4 mm long, 129.8 mm high, and 205.3 mm wide. The design of the Tunabot adopted a modular approach for the purpose of easy maintenance and upgrade. Each module has a unique function and can be altered independently, which significantly reduces the design iteration cycle time and overall cost. Current work is focusing on pitch and yaw control of the Tunabot. A multi-sensor fusion and trajectory control algorithm was developed and applied to the system. The effect on pitch control was investigated with different size of the pectorals fins based on previous biological data. Yaw was controlled by asymmetric tail flapping. Finally, the kinematics of the autonomous Tunabot are compared to data obtained from live tuna and from the laboratory test-platform version of the Tunabot.

62-2 ZHU, R*; MATTHEWS, DG; WANG, J; LAUDER, GV; DONG, H; BART-SMITH, H; University of Virginia, Harvard University; *rz6eg@virginia.edu*

Effects of Peduncle Stiffness on Propulsive Performance of Tuna-shaped Panel

Peduncle joint is an essential part of tuna swimming. Here we propose a simplified panel model to study the effects of peduncle joint stiffness on swimming performance. We use composite 3d-printed structure to vary the stiffness around the peduncle region and measure the thrust and power consumption at a wide range of swimming kinematics with different frequency and heave amplitude. Flow structure around the panel in high-performance cases is also visualized using Particle Image Velocimetry and Computational Fluid Dynamics.

S1-4 ZIEGLER, AF*; HAHN-WOERNLE, L; POWELL, B; LUNDESGAARD, Ø; CAPE, M; SMITH, CR; University of Hawaii at Manoa, Honolulu, HI, University of Hawaii at Manoa, Honolulu, HI and Norwegian Polar Institute, Tromso, Norway, University of Washington, Seattle, WA; *ziegler8@hawaii.edu*

From Glaciers to Benthos: Fjord Ecosystem Processes in a Changing Climate

Glaciomarine fjords of the West Antarctic Peninsula (WAP), e.g., Andvord Bay, form distinct hotspots of benthic biomass/diversity. Important drivers of these patterns may be 1) enhanced fjord primary productivity and export flux, and 2) limited larval dispersal from restricted fjord circulation. We found during our FjordEco Project that inner-middle Andvord Bay experiences limited meltwater/sediment input, high annual primary production, and high export flux, all of which support high benthic respiration and macro-/megafaunal abundance and biomass. Massive phytodetritus deposition mid-fjord in Jan 2016 led to rapid feeding by deposit-feeders yet still produced a substantial sediment food bank to sustain detritivory throughout the winter. To explore the influence of larval dispersal on benthic community structure, we used a high-resolution hydrodynamic/particle-tracking model to simulate larval transport. Larval dispersal between fjords is limited on ecological time and space scales due to weak circulation in most parts of the fjords. Occasionally, katabatic wind events may export near-surface larvae (

109-2 ZIKELI, S*; YAMADA, K; YAP, K; ZHANG, Y; KIARIS, H; HOOD, W; Auburn University, University of South Carolina; *slz0001@auburn.edu*

Shy and Stressed? Correlations Between Corticosterone Level, Unfolded Protein Response, and Animal Personality

Variation in animal personalities has been linked to experience and response to stressors. The stress response has been traditionally evaluated by quantifying glucocorticoids yet, individual variation exists in how animals, and presumably cells, respond to a similar signal. One intracellular process that likely underlies variation in the response to stress is the unfolded protein response (UPR). The variation in UPR has been shown to correlate with the several variables relevant to human health, but our understanding of the ecological relevance of variation in UPR is poor. To evaluate the relationship between the UPR and animal personality, we use deer mice (Peromyscus maniculatus) as a model, as they have been shown to display considerable individual variation in UPR. Prior to the onset of this study, responsiveness in cultured fibroblasts to tunicamycin, a compound stimulating protein unfolding, was quantified for each mouse by evaluating the relative expression of different molecular chaperones. The mice were then released into semi-natural enclosures where behavior was quantified. The behavioral tests included a novel object test, handling test, and predator cue test. Fecal samples were collected from individuals monthly to evaluate corticosterone.. We predict that animals with bolder personalities, and more ‘extreme' behavioral responses, will show greater capacity to perform under stress, i.e. display a relatively high UPR phenotype. These bolder animals may also have lower baseline corticosterone. Together, these data could help to illuminate the necessity of acknowledging individual variation at the cellular level and may identify the UPR as a modifier of the stress response at the organismic level.

15-6 ZUMAJO-CARDONA, C*; AMBROSE , BA; The New York Botanical Garden; The Graduate Center-CUNY, The New York Botanical Garden; *czumajo@nybg.org*

Evolution of the integument and its implication in seed plant evolution.

Gene duplication plays a decisive role in organismal diversification and the appearance of novel structures. One of these novel structures are the ovules/seeds which have unique morphological characteristics across seed plants. The genetic mechanisms regulating ovule development have been identified in Arabidopsis thaliana. The initiation of the ovule development appears to be mainly controlled by SEEDSTICK, BEL1 and AINTEGUMENTA. The Arabidopsis ovule has two integuments covering the nucellus. The asymmetric growth of the outer integument reorients the ovule resulting in an anatropous orientation. While BEL1 establishes the initiation of the integument development, INNER NO OUTER (INO), KANADI1 and 2 (KAN1/2) act in the proper development of the outer integument and ABERRANT TESTA SHAPE (ATS/KANADI4), is involved in outer integument development and the proper separation of both integuments. UNICORN (UCN), acts in the outer integument, repressing ATS. SHORT INTEGUMENTS1 (SIN1) is involved in cell elongation of both integuments and the sin1 mutant integuments do not cover the nucellus. We made a comprehensive search of these genes involved in the correct morphological development of the integuments to assess large scale duplications in addition, to expression analyses in the gymnosperm Ginkgo biloba. Our results show that each of these genes has undergone a different evolutionary history across seed plants and that the expression patterns are not conserved between Arabidopsis and Ginkgo. Our results suggest that the integument development network is not conserved between angiosperms and gymnosperms. We analyze the possible impact of these results on the morphological evolution of ovules as well as on the evolution of major seed plant lineages.