49th Annual Symposium

North American Society for Bat Research

Kalamazoo, MI, USA
October 23-26, 2019

Local Hosts
Amy Russell & Maarten Vonhof
Program Directors
Gary Kwiecinski, Shahroukh Mistry, Riley Bernard, Luis Viquez-R. and Emma Willcox

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Abstracts below for both platform and poster presentations are listed alphabetically by first author's last name. Contact information for authors attending the 49th NASBR Symposium is listed in the printed Program.

Bat Longevity is Predicted by Genome Methylation Rate

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Recorded lifespans of bats exceed other placental mammals of similar body size. Moreover, considerable variation in lifespan is present among bats with at least four lineages exhibiting extreme longevity. The underlying mechanisms of increased longevity are still unknown, but humans and other model species exhibit consistent age-related change in DNA methylation patterns across thousands of conserved sites. Using a custom microarray, we obtained methylation scores at more than 20,000 genomic sites from over 700 individuals of known age from 28 bat species representing six families. Using a machine-learning technique we derive a highly predictive relationship for estimating age in each species from a subset of these sites. We then use this relationship, or epigenetic clock, to estimate the age of unknown individuals as well as compare patterns of age-specific methylation acceleration and deceleration among species. We find that among species the rate of methylation change is significantly associated with maximum longevity, such that longer-lived species show slower rates of methylation change. In addition, using methylation data from six species with published genomes, we find that the majority of age-related methylation sites are near the transcription start sites of genes that are important for transcription regulation. We then further explore how the genomic regions with age-dependent methylation patterns vary among long and short-lived species.

Improving Urban Habitats for Bats: What Makes a Bat-friendly Residential Swimming Pool?

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For urban environments to support an abundant and healthy bat community, resources for a diversity of species need to be readily available, including roosting sites, foraging opportunities, commuting routes, and water sources. For example, bats typically have been recorded using water sources in urban areas, such as drainage ditches, lakes, and ponds. However, in areas where temperatures are consistently high and rainfall limited, these sources tend to be ephemeral. During these periods, bats have been observed utilizing an alternative water source in the form of residential swimming pools. Thus, if such pools can be

made more attractive to bats, this could be a strategy implemented to improve urban habitats. We, therefore, set out to determine what features, primarily size, shape (round or square), lighting, and treatment (chlorine, salt, mineral) encouraged bats to drink at pools. From June to September 2016 and 2019, we conducted behavioral surveys at 14 pools in suburban Fort Worth, Texas. Using thermal cameras and acoustic detectors, we recorded bat foraging and drinking activity. Our results to date demonstrated that while shape did not influence pool use, treatment type, lighting, and size did. For example, bats were observed drinking more readily at mineral pools. Pools with flood lights on all night were avoided entirely by bats, and all species (7 in total) were recorded at pools that exceeded 40 m^2 in size. With this information, we can better advise interested residents in urban neighborhoods how to make their backyards more bat-friendly.

Population Genetic Analysis of the Big Brown Bat in the Eastern United States

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The big brown bat (*Eptesicus fuscus*) is an ideal species for population genetic analyses because it is widely distributed, is believed to have a partial migratory strategy, and appears to be minimally affected by white-nose syndrome (WNS). In this study, we estimated genetic diversity, population structure, population connectivity, and population size trends by analyzing the cyt-b gene from big brown bats sampled across seven states in the eastern United States. We found some genetic differentiation among populations and high haplotype diversity. Bayesian clustering using the program Structure and model-based-distance clustering revealed two subpopulations. A Bayesian skyline plot analysis showed a decline in populations of big brown bats over time. In addition, we found a signal of positive selection in the cyt-b gene, concordant with the hypothesis that OXPHOS genes are under selection in bats because of the importance of energy demand. Also, the haplotypes differed from the cyt-b gene deposited in the National Center for Biotechnology in six amino acid substitutions, such as a cysteine/glycine to alanine. These data show high dispersal and connectivity among big brown populations, although some regional clustering does occur, and that although the species is thought to suffer low mortality from WNS, populations have been declining for around 2,000 years with a recent acceleration in this process. Given the importance of bats as pollinators, seed dispersers, and plague controllers, these findings of positive selection and population contraction encourage additional investigation to identify the selective pressures and the extent of population decline using nuclear data.

The Role of Temperature in Assemblage Structure of Overwintering Insectivorous Bats

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While community structure is typically considered to result from long-term ecological and evolutionary processes, behavior and physiology of temperate bats combined with variable environmental conditions can result in dynamic assemblages that vary from day to day. Overwintering insectivorous bat assemblages in temperate regions are one example, although the rules governing their structure are poorly understood. When faced with elevated thermoregulatory costs and reduced prey availability in winter, many bats opt to hibernate or migrate, but some populations, especially at southern latitudes, regularly fluctuate between using torpor and remaining active depending on environmental conditions\. This effectively removes or reintroduces species on a nightly basis resulting in a dynamic assemblage. In this study, we aim to understand the role of ambient temperature in determining bat activity based on species-specific thresholds. From December through March 2018 and 2019, we recorded bat activity at 72 sites in managed conifer forests of central Louisiana and eastern Texas. Over 1,568 detector nights of recording yielded approximately 37,000 bat passes representing all 12 species expected to occur in the region. Species richness was highly correlated with temperature and species-specific activity profiles were characterized by temperature thresholds. These results suggest that temperature significantly influences community

structure in overwintering bats potentially due to species-specific morphological, behavioral, or phylogenetic characteristics. Future research will investigate how temperature affects bats across a latitudinal gradient and how species characteristics and local adaptations combine to structure bat communities.

Factors Influencing Bat Occupancy of Artificial Roost Boxes

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Provisioning bats evicted from manmade structures with artificial roost boxes is a common strategy for mitigating the negative impacts exclusions have on bats; however, formal assessment of the effectiveness of this practice is rare. Using data from two bat conservation programs in New Jersey (Rutgers University Wildlife Conservation and Management Program and Conserve Wildlife Foundation of New Jersey), we explored factors significantly affecting occupancy rate of artificial roost boxes. We extracted from the dataset information on roost box occupancy, age (time since installation), placement (building, tree, or pole), and whether or not an exclusion had been performed in the property. We also tested the influence of multiple physical characteristics (i.e. color) of the roost box, as well as landscape factors (i.e. distance to water). Overall, 27% of roost boxes were occupied by bats. Predictor variables explaining the majority of variation in occupancy included roost box age, placement, and exclusion history. Roost boxes mounted on buildings had a significant positive effect on occupancy and increased with time since roost box installation. Occupancy was also highly dependent on whether or not an exclusion had been performed on the property; 86% of roost boxes installed on a building after an exclusion were occupied. Our results provide support for installing artificial roost boxes to mitigate negative impacts to evicted bats and provide justification for mounting roost boxes on structures close to the original roost entrance.

A Cross-taxa Test of Hypotheses for Why Bats Are Killed by Wind Turbines

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Wind turbines are a rapidly increasing means of generating electricity, and although wind energy is relatively environmentally friendly, it is not without ecological impacts. One concern is the large number of bats killed at some wind energy facilities. While there are many hypotheses that have been proposed to explain these fatalities, currently there are no definitive answers. We took a novel approach to evaluate the various hypotheses by using data on fatality rates of Nightjars (Order: Caprimulgiformes), a threatened avian Order that are ecologically similar to the bats killed most frequently at turbines across North America, the Lasiurine bats. We predicted that if the reason for collisions is general to nocturnal aerial-hawking insectivores, fatality rates at wind turbines should be similar across taxa. If fatality rates differ across taxa, then the reasons for fatalities are more specific to the Lasiurine bats. We used the Bird Studies Canada Wind Energy Bird and Bat Monitoring Database for data on fatality rates within Canada and the American Wind Wildlife Information Centre Database for data on fatality rates within the United States. These data indicate that fatalities of Nightjars at wind turbines are three orders of magnitude lower than for bats, even at the same sites. This lends support to the idea that the reason for high numbers of bat fatalities is related to being a bat (e.g. roost attraction, mating behavior, and/or anatomy) and not to being a nocturnal aerial-hawking insectivore (i.e. foraging).

Preliminary Analyses of the Roosting and Foraging Ecology of *Myotis lucifugus* on Prince Edward Island

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The behavioral ecology of post white-nose syndrome *Myotis lucifugus* on Prince Edward Island (PEI) is poorly understood, but the geography of Prince Edward Island National Park (PEINP) represents a unique opportunity to examine the habitat use of these endangered bats. The national park is long and narrow, abutting the ocean along its entire northern border and populated farms and towns to the south. Unlike other study areas which are often strictly forested or residential, PEINP has ocean, forest, and populated regions within the foraging range of *M. lucifugus*. We anticipate that the roosting behavior of bats foraging in the park can give insight to roost preference. If *M. lucifugus* prefer anthropogenic roosts to natural ones, then we expect our tracked bats will generally leave the park to roost in areas with a higher density of buildings. We netted for bats using mist-nets at sites across PEINP from June 5 until August 13, 2019, and tracked a subset of the captured bats to diurnal roosts using radio-telemetry. We primarily caught female bats, and most tracked bats used anthropogenic roosts outside the park. We propose using our second field season to sample at non-park sites comparable to park ones to see if roost preference is influenced by tree cover and housing density. Additionally, we hope to characterize important characteristics of anthropogenic roost structures. Early evidence supports the contention that PEINP represents important foraging habitat, and that the relationship between homeowners and roosting bats is key to the persistence of *M. lucifugus* on PEI.

Bats Draw Undergraduates into Studying Mathematics and Biology Together

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Once upon a time, a biology major could graduate with a B.S. degree with little or no mathematics on their college transcript. Times have changed. Accessibility to low cost data storage and high-speed computing power has transformed the academic study of biology, and the open source software movement has made world-class statistical and modeling software available to biologists in every area (*e.g.*, R, Octave, Python). While the undergraduate curriculum in biology has been slow to keep pace with these changes, professional societies and professional societies and foundations have invested in programs that aim to transform undergraduate degree programs to reflect the reality of the 21st century. This poster describes how we have used the beauty of bats (and NSF seed funding) to develop an interdisciplinary training program to prepare undergraduates to work at the intersection of the life and mathematical sciences. We describe how the natural history of bats provides an excellent platform for motivating students in biology and mathematics to work in an interdisciplinary fashion. Specifically, we use the question of finding (foraging) bats, acquiring their foraging acoustics, and then identifying them to species using machine learning techniques (*e.g.,* discriminant function analysis).

Multi-dimensional Resource Use by a Southern Appalachian Bat Assemblage

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Ecological niches are multi-dimensional, but multi-dimensional analyses of bat resource use are uncommon. Understanding how bat assemblages are structured may be enhanced by multi-dimensional, assemblage-wide studies of resource use. We conducted such an analysis for a Southern Appalachian bat assemblage via a spatially-distributed acoustic survey at 50 random sites in Great Smoky Mountains National Park, sampling from May–August 2015–2016. We deployed Pettersson D500X detectors on trails

and early successional openings, parsing calls into Myotis, Mid, and Low phonic groups. We tested 12 generalized linear mixed-effect models quantifying bat acoustic activity as a function of distance to water, proportion of forest in 500-m buffer, basal area, and canopy closure, using an information theoretic approach to compare models. We assessed use of 4 major habitat types via ANOVA. We used a non-parametric kernel density estimation procedure to describe trends and examine degree of temporal overlap in activity among phonic groups. Myotis and Mid bats exhibited the greatest proportion of temporal overlap, but differed spatially. Myotis focused activity at sites with more forest in a 500-m buffer and used northern hardwood forest most often and early successional habitat least often. Mid bats used early successional habitat most often and spruce-fir forests least often. Temporally, Low bats overlapped least with Myotis, but Low bats showed no significant spatial variation in habitat use. This Southern Appalachian bat assemblage uses resources in complex ways that may not be apparent by spatial analyses alone. Future studies should examine temporal and dietary dimensions of resource use.

Microbiome Classification Studies of *Myotis sodalis* with Further Identification of Microbiome Chitinase-producing Bacteria

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Bats serve a very valuable role within the environmental and human world. They are responsible for a multitude of beneficial processes, such as, aiding in the control of disease, pollination, and seed dispersal. Since its emergence in 2006, white-nose syndrome (WNS) has caused a large decline in bat populations. Interestingly, some bat species experience illness from *P. destructans* while other species do not. Could it be the microbiome plays a role in protecting bats? We aimed to collect and characterize bacteria from the microbiome of WNS-affected *Myotis sodalis* and identify any chitinase-producing bacteria that has the ability to break down chitin. We collected samples from *M. sodalis* via swabs of the surface skin in the oral, wing, and genital regions of bats caught by harp trapping and mist netting in Missouri and Indiana. The characterization of the microbiome and identification of chitinase-producing bacteria is done through isolation and differential hands-on lab techniques. Bacteria will be characterized down to genus. Results gathered from this work will be beneficial to aide in the relation of bats and their microbiome influence to possible disease susceptibility or defense. With the detrimental decline of bat populations, especially within the endangered North American species, research to broaden what we know has only become even more prevalent.

Multi-species Roosting May Bias Emergence Count Surveys in Eastern North America

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Emergence counts are frequently used as a low-impact method of monitoring bat populations. However, it is difficult to identify the species of individual bats when employing this method. Thus, most researchers assume that all bats that emerge from a roost are the same species. This is a risky assumption that, if proven false, could greatly impact estimates of population size. To determine the prevalence in which this assumption is broken, we requested data from bat biologists working in the eastern United States. We received data from nine researchers that confirmed the occurrence of roosts containing multiple species of bats on a single day (multi-species roost). Reported multi-species roosts included large bridge roosts, bat boxes, BrandenBark artificial roosts, and tree roosts. These roosts contained combinations of nine bat species; *Myotis sodalis*, *M. lucifugus*, *M. septentrionalis*, *M. grisescens*, *M. leibii*, *M. austroriparius*, *Nycticeius humeralis*, *Corynorhinus rafinesquii*, and *Eptesicus fuscus*. Within these multi-species roosts, one individual bat species was typically found in numbers that comprised the majority of occupants, while other species of bats were found in numbers higher than anticipated (i.e. more than one individual bat/outlier) The average percent composition of an individual species within a multi-species roost was 38.6 ± 0.3%. These results suggest that multi-species roosts do occur, and the number of bats of non-target

species in each roost may not be negligible. Biologists should consider this potential bias whenever employing emergence counts as a method to survey bat populations.

Is There a Silver Bullet for Managing White-nose Syndrome? Comparing Management Decisions across Pathogen Emergence Zones

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In the last decade, federal, state, and provincial agencies, tribal and private organizations, and academic institutions have collaborated on developing surveillance, monitoring, research, and management programs for white-nose syndrome (WNS). As a result, scientists and managers have learned a great deal about variations in host ecology and pathogen dynamics; however, effective mitigation measures to combat the disease remain elusive. To address this mismatch between research and management, we used decision analysis to assist wildlife managers located within each WNS pathogen zone (i.e., WNS Confirmed, *Pd* Detected, and *Pd* Not Detected) to identify management strategies for bat populations of concern. Across these decisions, we identified differences in how each manager approaches and implements actions to prepare for, or combat, WNS. We completed three workshops and found that management objectives and actions were consistent across managers and pathogen zones. Here, we present common themes and risk profiles that may aid in the development of conservation strategies in other management jurisdictions, as well as other disease systems.

Midnight Snack: Investigating the Consumption of Prey by Bats during Hibernation in Tennessee

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Temperate North American bat species use seasonal hibernation to conserve energy when ambient temperature is low and food resources are scarce. Previous research suggests that migratory species, such as tree bats, and species known to roost in thermally unstable locations are more likely to remain active throughout winter. Recently, studies conducted in the southeastern U.S. documented emergence activity of cave roosting species throughout the hibernation period. To determine if individuals were foraging during periodic winter arousals, we captured bats emerging from five caves in Tennessee over the course of six winters (October–April 2012–2018). We used NextGen sequencing to analyze guano from 455 individuals, representing 10 species of bats. We analyzed 116 samples using the Ion Torrent platform for guano collected during winters 2012–2014 and 339 samples using the Illumina MiSeq platform for guano collected during winters 2014–2018. Our objectives were to 1) determine the composition of prey consumed by bats during winter; 2) identify the differences in the consumption of prey consumed among species. A total of 1,990 Operational Taxonomic Units (OTUs) were consumed by bats active in winter, with 1,175 (~ 60%) identified to species or order in BOLD. Bats captured during winter consumed a much wider variety of insects than expected. By gaining a better understanding of what bats are consuming during winter, we may be able to manage for, and promote the availability of, targeted insect prey known to be consumed during a time when bats are most vulnerable to disturbance or disease.

Response of Bats and Nocturnal Food Webs to Mountain Pine Beetle Outbreaks

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Climate change is causing increasing severity and frequency of disturbance events, altering community compositional structure and food web interactions. Bat ensembles exert top down food web influences and are sensitive to disturbance events that alter prey composition and habitat structure. Severe outbreaks of mountain pine beetle (*Dendroctonous ponderosae*) in Colorado impacted over 1.3 million hectares of lodgepole pine (*Pinus contorta*) forests, resulting in widespread defoliation. The secondary successional stages that ensue are linked with changes in insect composition, and bats limited by ecomorphology are expected to respond to changes in habitat structure and prey availability. We conducted an exploratory survey in Roosevelt National Forest, Colorado to identify how mountain pine beetle (MPB) affected lodgepole pine forests have disrupted bat habitat-specific foraging patterns and nocturnal insect abundance and composition. We expect activity of maneuverable, gleaning bats and insect abundances to be greater in severely affected stands than in unaffected stands. We deployed SM2 Wildlife Acoustics bat detectors in severely affected ($\geq$50% stand mortality) and unaffected ($\leq$10% mortality) lodgepole pine stands from June to August 2019 to survey bat activity. We used a Townes Style Malaise trap to determine nocturnal flying insect abundance and composition and quantified understory and overstory vegetation structure at each detector location. Preliminary analyses showed high bat activity in severely affected stands with higher degrees of coarse woody debris (CWD) and understory cover. We hope to quantify how the progression of large-scale successional changes of beetle affected forests alter competitive interactions among foothill bat ensembles.

Myotis sodalis and *M. septentrionalis* Captures and Roosting Preferences in Post White-nose Syndrome Missouri 2017–2019

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North American bats are facing precipitous declines from climate change, energy development, and white-nose syndrome (WNS). WNS was first detected in Missouri in 2010 and since 2012 there have been large population declines among the cave hibernating species. We conducted mist-net surveys during the summer maternity season at six Missouri Department of Conservation lands in northern Missouri over three years. A total of 632 bats representing 9 species were captured over 500 mist-net nights. Thirty-nine *Myotis sodalis* were captured in 2017, 9 in 2018, and 8 in 2019 whereas 5 *M. septentrionalis* were captured in 2017, 1 in 2018, and 0 in 2019. We compare roost radio telemetry results with resource use studies for *M. sodalis* and M. *septentrionalis*. Of note, *M. sodalis* maternity colonies roosted in cracks and crevices in snags with little or no bark on a lake rather than roosting beneath exfoliating bark. Wildlife managers can use this information and approach to evaluate bat population trends in the post-WNS Midwestern landscapes to design and implement appropriate conservation strategies.

Specialized Landing Maneuvers in *Thyroptera tricolor* Reveal Linkage between Roosting Ecology and Landing Biomechanics

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Disk-winged bats (*Thyroptera* spp.) are the only mammals that use suction to cling to smooth surfaces, having evolved suction cups at the bases of the thumbs and feet that facilitate attachment to specialized roosts: the protective funnels of ephemeral furled leaves. We predicted that this combination of specialized morphology and roosting ecology is coupled with concomitantly specialized landing maneuvers. We tested this prediction by investigating landings in *Thyroptera tricolor* using high-speed videography and a force-measuring landing pad disguised within a furled leaf analogue. We found that their landing maneuvers are distinct among all bats observed to date. Landings comprised three phases: 1) approach, 2) ballistic descent, and 3) adhesion. During approach, bats adjusted trajectory until centered in front of and above the landing site, typically the leaf's protruding apex. Bats initiated ballistic descent by arresting the wingbeat cycle and tucking their wings to descend toward the leaf, simultaneously extending the thumb-disks cranially. Adhesion commenced when the thumb-disks contacted the landing site. Significant body reorientation occurred only during adhesion, and only after contact, when the thumb-disks acted as fulcra about which the bats pitched 75.02 ± 26.17º (mean ± s.d.) to swing the foot-disks into contact. Landings imposed 6.98 ± 1.89 bodyweights of peak impact force. These landing mechanics are likely influenced by the orientation, spatial constraints, and compliance of furled leaf roosts. Roosting ecology influences critical aspects of bat biology, and taken as a case-study, this work suggests that roosting habits and landing mechanics could be functionally linked across bats.

Bat Activity at Vernal Pools in California

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Vernal pools are a protected yet diminishing habitat in the Central Valley of California. These shallow, ephemeral wetlands have an impervious hardpan, filling with rainwater during winter and spring, but are dry throughout the summer and fall. They are home to several rare and endemic species of plants and animals. Vernal pools may provide a habitat for bats to forage as well as access to water during the spring, especially as surrounding habitats dry, yet there are no studies of bat activity at vernal pools in California. We hypothesized that bats would utilize these habitats to forage and drink. Acoustic recorders were deployed at Pool 22 of the Vina Plains Preserve in Tehama County to record nightly, starting on April 20, 2019. There was significant bat activity – almost exclusively *Tadarida brasiliensis* – at the vernal pool during the spring, and this reduced in summer as the pools dried. Activity at the pool was considerably higher than at a control site one km away – averaging 43 and 5 passes per night respectively. Bat activity also surprisingly rebounded during late July and August, perhaps indicating changes in insect availability. Peak *Tadarida* activity was 8:00 to 10:00 pm and then again at 4:00 am, whereas *Myotis* spp. were most active between 1:00 and 3:00 am. Preliminary analysis indicates at least 20%, and up to 60%, of nightly bat passes included feeding buzzes, suggesting that vernal pools are actively used by bats as foraging habitat.

Synchronous Muscle Recruitment for Stable Flight Control in Egyptian Fruit Bats

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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.

Size Matters: Evidence of Resource-defense Polygyny in a Subtropical Bat

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Understanding social structure and animal behavior is critical for effective species conservation. Many tropical bat species form harems, where males play key social roles by defending groups of females directly (female-defense polygyny) or the resources that females need (resource-defense polygyny). *Eumops floridanus* (Florida bonneted bat) is an endangered subtropical species thought to form harems, but our understanding of its social structure, reproduction, and behavior is rudimentary. Here, we evaluated demographic variation in morphology and behavior of *E. floridanus* to determine if this species may exhibit female or resource-defense polygyny. We used a three-year dataset of 341 individuals uniquely marked with Passive Integrated Transponders (PIT tags), coupled with tri-annual capture records, to track bats at 5 roosts fitted with PIT tag readers. We identified likely dominant males in each roost using morphometric and reproductive status characteristics. We assessed differences among sex, and status categories in three primary metrics: roost activity, emergence times, and foray duration per night. Large, dominant males were more active at roosts, spent less time foraging and returned to roosts more frequently during the night than females and other smaller males. Females spent the most time foraging regardless of reproductive status. We provide evidence that *E. floridanus* forms small harem groups that are active year-round and exhibits resource-defense polygyny, with the largest males defending the roost at the expense of time spent foraging. We suggest that roost sites represent critical resources for male *E. floridanus* to recruit and gain access to females, which has important implications for conservation.

Do Bats Use Olfactory Cues to Locate Potential New Roosts?

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Understanding how bats select roosts is crucial to their management. This knowledge could help exclude bats from buildings and attract them to protected areas. Research on how bats locate roosts has focused on acoustic cues. Other studies have found effects of scent-marking. However, inadvertent chemical cues in bat guano and urine might also influence roost-finding. To test this hypothesis, I ran a series of tests to see if bats chose to roost in sites stained with guano and urine, using vampire bats (*Desmodus rotundus*) and velvety free-tailed bats (*Molossus molossus*) in Panama and big brown bats (*Eptesicus fuscus)* in Ohio. To measure attraction to scent cues, I filmed captive bats (24 *Desmodus* and 18 *Molossus*) in an experimental arena. To count visits to roosts in the field, I used paired ultrasonic microphones installed within two adjacent experimental roosts, where one roost entryway was stained with guano and urine, while the other served as an unscented control. Roosts were deployed at 16 sites in Panama and seven sites in Ohio. To test the impact of acoustic cues, I played back calls of bats between the two roosts. Preliminary analysis suggests that (1) scent from guano is not a strong enough attractant to draw bats into new roosts and (2) captive bats are not immediately attracted to guano scent, but they appear to show a preference to roost in the scented sites after longer time intervals. Our work gives insight on the capacity for scent cues as a tool for bat management.

Integrative Maps for Bats of the World

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Spatial data are essential for visualizing the distribution of bats, environmental gradients, landscape genetics, and temporal changes to promote and inform research and sustainable management decisions. As known bat species diversity continues to increase, spatial data to create geographic distribution models are in high demand. Recognizing the limitations of all spatial data is essential as there are many primary open source data sets available. In an effort to visualize the most probable distribution for each species represented on the Bats of the World: A Taxonomic and Geographic Database (www.Batnames.org), two open source spatial data sets were used for the species distribution maps. The IUCN Red List polygon data represent the conservative distribution layer, while gbif point data were incorporated using a more discriminatory approach by developing a "potential outlier" layer for all points that exist outside of the IUCN polygons. ArcGIS Pro Version 2.4 was used to create the geospatial layers in a coordinate system based on each species geographic range in an effort to reduce distortion for shape, area, distance, and direction. Metadata were updated for all species-specific map layers and then configured to a species Webmap through the Portal into ArcGIS Online. Species Webmaps were reprojected to the WGS 1984 Web Mercator Auxilliary Sphere prior to being linked to the website as interactive species maps. We hope to update all the bat species Webmaps prior to the next biannual review by the Global Bat Taxonomy Working Group of the IUCN Bat Specialist Group in the fall of 2019.

Bats of the California Channel Islands: New Records with New Methods

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Eight bat species were known and documented from the California Channel Islands when J.C. Von Bloeker (1967) presented at the First California Islands Symposium in 1965. Methods of detecting and identifying bats have changed over the past century (Brown and Rainey 2018). Museum collection methods using shotguns have been replaced by mist-netting and recording of echolocation signals. Currently, capture

or acoustic records have identified 14 bat species (56% of the 25 species known to occur in California) on six of the eight California Channel Islands, with occasional sightings of flying bats on the other two. Bats now compose 78% of the native mammals on the islands (Collins 2012). Recorded echolocation signals are now recognized as valid "vouchers" if the species emits calls that are separable from others. For year-round monitoring, the authors have installed long-term acoustic recording equipment on three of the islands. For example, echolocation signals have identified western red bat (*Lasiurus blossevillii*), hoary bat (*Lasiurus cinereus*), western yellow bat (*Lasiurus xanthinus*), and Mexican free-tailed bat (*Tadarida brasiliensis*) from San Nicolas Island, and western mastiff bat (*Eumops perotis*) and canyon bat (*Parastrellus hesperus*) from Santa Cruz Island. Acoustic data have identified three new species for the California Channel Islands, as well as several new records on individual islands. As acoustic monitoring and other techniques are used more extensively, the number of species documented will increase and the proportions that are resident, vagrant, or transient on each island can be better resolved.

Effect of Flight Duration on ß-hydroxybutyrate Concentration in Blood Plasma of *Eptesicus fuscus*

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Insectivorous bats alter relative use of metabolic substrates to match requirements of their activities, including energetically expensive flight. The "fasting while foraging" hypothesis states that the metabolic demands of flight often exceed energy intake while foraging, hence bats may metabolize fat stores (especially early in the night) to power flight with ketones, a byproduct of the normal oxidation of fatty acids. Previous studies in bats found increases in the plasma ketone ß-hydroxybutyrate following food consumption paired with or without flight, but no study has explored whether increases in plasma ß-hydroxybutyrate occur following flight without food consumption. We used metabolite analysis to examine changes in plasma ß-hydroxybutyrate as a function of flight duration in 2 groups (fall and spring) of captive big brown bats (*Eptesicus fuscus*). We fasted bats for 12 hours prior to flight (exercise treatment) or rest (control), and then collected interfemoral vein blood. Exercise activity was quantified as flight time. For the fall group, we collected three rest and one flight sample. Results for the fall group were mixed and the interpretation of data patterns may be complicated by changes in metabolism that occur in the Fall when bats physiologically prepare for hibernation. To control for seasonal effects, group 2 bats were tested in the spring, and we collected two rest and three flight samples. We found a positive correlation between flight duration and levels of plasma ß-hydroxybutyrate in the spring group, which supports the fasting while foraging hypothesis.

Anthropogenic Effects on Landscape Connectivity in Bat Communities of Puerto Rico

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The current biodiversity crisis is driven by anthropogenic (e.g. habitat transformation) and natural (e.g. hurricanes) disturbances that can disrupt connectivity and lead to extirpation or extinction. The Caribbean is a biodiversity hotspot with a high rate of mammal diversity loss since the Last Glacial Maximum. Puerto Rico, one of the most isolated islands in the Caribbean, is home to 13 bat species that inhabit three different ecosystems: tropical moist and dry forests, and Bahamian-Antillean mangrove forests. These ecosystems have been subjected to different levels of disturbance over time, providing a living laboratory to investigate the effects of anthropogenic and natural disturbances, and evaluate potential threats to bat dispersal, survival, and population recovery. Here, we use circuit and graph theory to quantify structural connectivity between 53 unique localities on Puerto Rico across these ecosystems. We built a

network of bat communities using similarity and geographic distances to identify important localities that serve as community connectivity corridors. Our results identify several urban (e.g. San Juan, Bayamón, and Toa Alta) and forest (e.g. Arecibo, Adjuntas, Lares, and Orocovis) localities that create corridors from East to West, with poor connectivity from North to South across the Central Cordillera. Northern urban localities still provide suitable habitat in small fragmented forest remnants, in contrast with localities with intense agricultural pressure in the south of the island. By defining and quantifying bat communities and connectivity, we can assess population changes and recovery in the face of global change.

Hydrogen Isotopes Reveal Complex Seasonal Migratory Structure in At-risk Tree-roosting Bats in North America

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Understanding migratory patterns is essential to predicting the impacts of, and organismal tolerance to, global environmental change. Several species of bat migrate long distances within North America, exhibiting potentially complex migratory structure. These species have been negatively impacted by human development during migration, and some might be at risk of extinction. However, bat migration has thus far been very difficult to study by traditional means. Stable isotope signatures present a promising alternative, but bat movement patterns have thus far been too complex to summarize within the context of small regions or distinct management units. Understanding of bat abundance and habitat usage is also limited, so it is difficult if not impossible to identify distinct regions of seasonal habitat. We used stable hydrogen isotope analysis in conjunction with emerging methods of analytically comparing probabilistic assignment models of animal origin to examine migratory structure in three species of North American tree-roosting bat. Our results indicate a strong signal of migratory structure in two of the three species, and the presence of partial migration (year-round residency of some individuals, up to very long-distance migration in others) in all three species. These results have important implications for understanding the migratory ecology, evolutionary ecology, and conservation risks facing these species.

Bats and Apples: Bat Ecosystem Services in Apple Orchards in Central New York

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New York is the second largest producer of apples in the United States. Conventional farmers reduce pest damage using pesticides. However, in addition to high economic costs, pesticides are toxic and decrease natural enemies and pollination services. Thus, many farmers have opted to use organic systems, but they experience higher crop damages. For years, we have known that insectivorous bats can suppress nocturnal insects. However, because this is not an obvious service, their value is not placed on its magnitude. Moreover, although multiple studies have looked at bat pest-control services in a variety of crops, the importance of bats in New York apple orchards has not been evaluated. Thus, we monitored presence of bats and pests in apple orchards, to estimate their pest-control value. So far, we have detected 8 bat species foraging in both conventional and organic orchards. The most common species is *Eptesicus fuscus*. This species is more active from 9pm to midnight, corresponding with the activity peak of the codling moth, the most common apple pest in the area. This suggests that *E. fuscus* is probably the most important pest-control species in the area. Currently, we are evaluating density and activity of pests and collecting bat pellets to estimate bat diet at apple orchards. With this data, we want to estimate the monetary contribution of bats as pest control. We are confident that our estimates will resonate in the scientific community, the general public, and policy-makers.

Vampire Bats that Cooperate in the Lab Re-form their Social Networks when Back in the Wild

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Behavioral ecologists disagree about the concept of 'social bonds.' Some authors argue that many animals form social relationships similar in form and function to human friendships. Others point out that such bonds are often defined using correlational social network data and many nonsocial effects can create these same patterns. Other authors argue that these patterns might be based on stable options of partners rather than on partner fidelity. Here we present a framework for resolving this controversy: social bonds exist but their existence alone cannot explain why animals cooperate because they vary along a spectrum of stability. Measuring relationship stability is therefore necessary to test the roles of partner control, partner choice, and threat of partner switching. We apply this framework to vampire bats. If social bonds actually cause social network structure, then social preferences tested under controlled conditions should predict association even in a drastically different physical and social environment. Using a recently-developed high-resolution automated proximity sensor system, we show that vampire bats that cooperate in the lab reform their social networks when released into the wild. Allogrooming and food-sharing induced in captivity among female vampire bats over 22 months predicted their assortativity and association rates in the wild. Not all social bonds survived. On one hand, social bonds are not an emergent byproduct of a stable captive environment and they are a cause rather than a mere consequence of spatial structure. On the other hand, the social environment matters and even strong social bonds are not entirely stable.

Mineralization of the Trachea and Larynx in Laryngeally Echolocating and Nonecholocating Bats

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Cartilage that forms the structural basis of the trachea and larynx in echolocating bats is often relatively heavily mineralized compared to those of other mammals. Mineralization is thought to reinforce the cartilage in response to forces applied through echolocation and possibly flight. Using computed tomography, I assessed the relative levels of mineralization of tracheal rings, cricoid, thyroid, and arytenoid cartilages in nonecholocating, low intensity low duty cycle, high intensity low duty cycle, and high intensity high duty cycle echolocating bats. All individuals showed evidence of tracheal ring mineralization. Larger bats exhibited more extensive tracheal ring mineralization compared to smaller bats irrespective of the ability to laryngeally echolocate. Surprisingly, nonecholocating bats had extensively mineralized cricoids and thyroids and no evidence of mineralization of the arytenoids. Low intensity low duty cycle bats only had mineralized cricoids. High intensity low duty cycle bats had patchy mineralization of the cricoids, thyroids, and arytenoids. High intensity high duty cycle bats had extensively mineralized cricoids and arytenoids and large sections of mineralization of the thyroids. The degree of laryngeal mineralization matched the presumed workload associated with the echolocation system, in that low intensity low duty cycle bats had the least amount of mineralization and high intensity high duty cycle bats had the most. None of the echolocating bats had completely mineralized thyroids, which may reflect a dynamic function, moving and distorting during sonar signal production. Whereas, the thyroids of nonecholocating bats may play a larger role in maintaining the airway during ventilation and require more rigidity.

1406 Reasons Why Diversity is Important

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What if biologists chose to study only one bat species in the world? Despite gaining tremendous understanding of the animal, this species would define our knowledge of Chiroptera. Everything we identified about behavior, diet, disease, echolocation, evolution, habitat use, hibernation, physiology, and reproduction would be focused through the lens of a single species. As biologists, we recognize this is a ridiculous proposition. Why then, should we be any less concerned about representing the full range of human qualities and attributes in our profession? A variety of genders, ethnicities, sexual orientations, perspectives, areas of expertise, and cultures leads to better science. Increases in productivity, creativity, and quality rise when women and historically underrepresented groups participate. Problem solving and collaboration among groups of people with diverse backgrounds and experiences leads to more innovative outcomes. Diverse groups of people raise different questions; questions drive science, and that moves science forward. For example, a First Nations woman wildlife biologist who studied gene flow and population structure developed a non-invasive approach to sample DNA. She helped establish the practice of using fecal samples for DNA collection. Despite these and other examples, we struggle to ensure equal representation. We are drawn to people who are like us. What challenges do women and minorities face to entering and excelling in science and the study of bats? What are practical approaches to increase, recognize, and encourage contributions of diverse people into this profession? We must recognize our biases, create connections, take action, and be allies to underrepresented groups. Those in leadership roles can recruit and train women and minorities, foster an open work culture, mentor, encourage cross-job communication and nonhierarchical structures, make sure women and underrepresented minorities represent 15 to 30% of team members to gain critical mass. We drive science forward when "we" represents all of us.

Collaborative Monitoring Strengthens Macro-scale Assessments of White-nose Syndrome Impacts for North American Bats

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In order to understand macro-scale population dynamics and impacts from perturbations operating at large spatial scales, monitoring at broad scales is imperative. The invasive fungal pathogen, *Pseudogymnoascus destructans* (*Pd*), causing the disease, white-nose syndrome (WNS) in hibernating bats, has caused severe, local declines and extirpations in several species of hibernating bats throughout North America. However, in order to examine macro-scale impacts of WNS on North American bat species, monitoring and assessment must be conducted at broad scales. The North American Bat Monitoring Program (NABat) was initiated in 2015 as the first broad-scale coordinated effort to monitor bat species across North America. Leveraging efforts by NABat, we used winter count data of five species of hibernating bats (*Myotis lucifugus*, *M. sodalis*, *M. septentrionalis*, *Perimyotis subflavus*, and *Eptesicus fuscus*) collected from the US and Canada at over 200 sites across 25 states and provinces, and spanning 23 years from 1995-2018. For four out of five species (*M. septentrionalis*, *P. subflavus*, *M. lucifugus, M. sodalis*), we found that WNS caused sustained declines greater than or equal to 90% and extirpations throughout their ranges following the invasion of *Pd.* Results at the macro-scale also indicate losses by an order of magnitude (log-scale) difference following *Pd* invasion for the same four species. Our study highlights the strength of macro-scale assessments that can only be derived from broad-scale monitoring

efforts, and which are needed to implement greater global, national, and state/province-level protection for the most impacted species.

Genetic Approaches Improve our Understanding of Bat-Wind Turbine Impacts

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Understanding the impacts of wind energy mortality on bats requires accurate assessments of species and sex, but this is not always possible in the field. This study applied a genetic approach to identify sex and species using bat carcasses collected during post-construction fatality monitoring from two wind energy facilities in south Texas in 2017 and 2018. This region has a diverse bat community with morphologically similar species, and early reports suggested that both *Lasiurus (Dasypterus) intermedius* and *Lasiurus (Dasypterus) ega* would be impacted. From these facilities, we obtained wing tissue samples from 440 bats identified as *L. intermedius* (66%) or *L. ega* (33%) in the field. Following DNA extraction, regions of the X and Y chromosomes were amplified using PCR to determine sex ($n = 412$) and a region of the mitochondrial COI gene was sequenced to verify species identification ($n = 426$). Field sex assignments were 18% female, 19% male, and 63% unknown, with no difference between species. Molecular data indicated a 53% female-biased sex ratio. *L. ega* had more field misidentifications than *L. intermedius* with 24% versus 8%, respectively. Sequencing data also revealed *L. xanthinus* ($n = 36$) and *L. blossevillii* ($n = 3$), two species that were not known to occur in this region of Texas. Our data indicate that molecular sex determination is necessary for studies investigating influences of sex on collision risk. We also recommend DNA barcoding be used for species identification in regions with morphologically similar bat species and where species of conservation concern could be impacted.

Understanding Migration Diversity: Connecting Migratory Patterns to Functional Motivations

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Each year billions of animals migrate between seasonally disconnected habitats, influencing the ecological properties of their temporary habitats and filling important ecological roles. Some species make 'to-and-fro' migrations, where all individuals move between seasonal habitats. But, for many species, migration patterns are more complex, involving partial and/or differential migration. Landscape-level patterns of migration are the cumulative result of the collective behaviors of individual migrants (migration is an adaptive trait expressed by individuals). Thus, to understand the adaptive drivers of population level migratory patterns, we must consider the functional motivations (i.e., the current fitness utility of a behavior) of migrating individuals, and how varied functional motivations within populations give rise to the observed diversity of landscape-level patterns of migration. In this talk, we will first describe a conceptual framework linking the functional motivations of migrants to landscape-level patterns of migration. The framework includes considerations of varied migration strategies that result in different flight and stopover behaviors throughout migration. We apply the framework to a system of long-distance migratory hoary bats (*Lasiurus cinereus*) that exhibit both partial and differential patterns of migration. We find that differences in reproductive contribution throughout the annual cycle between hoary bat sexes are a primary driver of the observed migratory diversity, demonstrating the influence of life history traits on migration. We conclude that our framework is useful for identifying critical natural history gaps, setting meaningful research trajectories for migration conservation, and understanding the evolution of migratory diversity.

Bat Activity on a Gulf Coast Refuge: Understanding Activity Patterns

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There is a lack of knowledge of bat ecology on the Texas Coast, which can guide conservation and management. Our objective was to compare bat activity on the San Bernard National Wildlife Refuge as a response to habitat type (bottomland hardwood, saline prairie, and upland prairie); habitat structure (field, open water, and corridor); and time of night. Preliminary data in a telemetry study suggested evening bats (*Nycticeius humeralis*; a species known to be relatively flexible in roost site selection) are not using the refuge for roosting; however, we predicted bats are traveling to the refuge to forage. We predicted bat activity would be greatest in the bottomland hardwood habitat, open water structure, and equally active throughout the night. We recorded activity with Pettersson D500X detectors on the refuge in summer of 2018 (n = 53 sites). We defined "high level of activity" as being above the 70th percentile of activity. We compared habitat type and structure using percent of nights with at least one hour of high activity and a balanced Analysis of Variance, and time of night by mean number of calls per hour of night and a Chi-square goodness of fit test. Bat activity was similar among habitats and hours (all p-values > 0.05). These results, coupled with the preliminary telemetry data, indicate bats are traveling to the refuge and foraging throughout the night on all areas of the refuge. Our management recommendation includes increasing availability of potential roosts throughout the refuge including large-diameter trees and bat boxes.

Shifts in Collagen Fiber Orientation with Age in Bones of Big Brown Bats and C57BL/6 Mice

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The wing bones of bats dynamically bend and twist with wingbeats. These bones are relatively long and circular in cross-section. Little is known of positional and age-related changes in the mineral density and orientations of collagen fibers (CFO) within wing bones. Here we employ directional statistics and multivariate analysis on data from quantitative polarized light microscopy (qPLM) to compare CFO across the lifespan of long-lived big brown bats (*Eptesicus fuscus*) and age-matched C57BL/6 mice. Within bats, wing bones displayed a proximodistal gradient in CFO anisotropy and longitudinal orientation, and density. The radius and metacarpals underwent stepwise declines in CFO with age, suggesting that the bone tissue was potentially modeled with age. Bones of middle-aged and elderly bats showed equivalent bone mineral densities and a distinct ring of helically-oriented endocortical tissue surrounding the medullary cavity. Bones of mice differed in that CFO didn't change between middle-aged and elderly cohorts, they achieved peak density at middle age, and either lacked or displayed a reduced endocortical ring of tissue. Bats therefore display a different pattern of limb skeletal aging compared to mice, and these differences may be associated with the unique skeletal performance and extended healthspan associated with a volant lifestyle in bats.

Open-source Software for Large-scale, High-throughput 3D Video Tracking of Bats

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Three-dimensional video tracking is a powerful tool for studying bat behavior in a variety of contexts such as roost exit counts, predator-prey and social interactions, and encounters with wind turbines. This technique usually requires specialized training and expensive equipment. Here, we present the current progress of a powerful open-source software platform that allows large-scale and high-throughput three-dimensional (3D) video tracking with minimal training. We discuss hardware solutions, comparing thermal and near-infrared cameras. We also demonstrate camera synchronization methods including electronic

impulses sent via dedicated cables *versus* acoustic signals broadcast to the camera audio channels. Finally, we demonstrate software tools that are in development for 2D tracking, camera calibration, and multi-object 3D tracking. Together, these tools will provide high-precision quantification of bat movements in a wide variety of contexts with minimal training and equipment.

Impact of Aspect on the Microclimate of Bat Boxes and Artificial Roost Selection of Indiana Bats

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Bat boxes are important conservation tools, providing roosting locations in altered or suboptimal habitats. Of the few designs tested, many findings suggest suboptimal temperatures for bats. In a pilot study, we analyzed the microclimate of a common bat box design from 23 August to 5 September, 2018 at an early-successional field site in Kentucky. Our objective was to develop a temperature profile for bat boxes in this habitat and to assess effects of aspect on box microclimate. We deployed boxes facing either east or north (n = 3 per orientation), and measured internal temperatures hourly. In both orientations mean daily temperatures varied by ~12ºC, and we observed no overheating (i.e., temperatures > 40 ºC). Compared to north-facing boxes, east-facing boxes were 0.4 ºC warmer on average, peaked in temperature later in the day, and retained slightly more heat at night. Building on these results, we have now deployed 40 rocket style bat boxes at sites in Indiana and Kentucky. A standard design is our control, while 2 designs are intended to increase minimum temperatures, and 2 other designs are intended to reduce maximum temperatures. We aim to profile the microclimate provided by each box in different landscape contexts and to assess the subsequent roost selection by Indiana bats (*Myotis sodalis*) in response to box design and environmental variables. Our results will provide insights into roost selection by Indiana bats, and will better inform resource managers as to the proper design, microclimate, and placement of artificial roosts.

Post-emergence Migration Patterns and Habitat Associations of Female Indiana Bats in Arkansas

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In Arkansas, hibernacula used by federally endangered Indiana bats (*Myotis sodalis*) are well-known, however, migration patterns and maternity colony site selection remains unclear. Vulnerability to disturbance during pup-rearing poses a significant risk to the species making it crucial to gain an understanding of their summer habitat use. Despite extensive survey efforts in Arkansas, little evidence about the existence of maternity colonies has been revealed. In 2006, one maternity colony was documented at the Dave Donaldson Black River Wildlife Management Area in Clay County, Arkansas. Additionally, in July 2015 a single post-lactating Indiana bat was captured in the Ozark-St. Francis National Forest – Big Piney Ranger District in Newton County, Arkansas. To better understand migration patterns and summer habitat use, we used radio-telemetry to track female Indiana bats from hibernacula to maternity roost sites in Arkansas during 2018 and 2019. Preliminary data generated in 2018 provided insight of initial migration trajectories, but no maternity colonies were located. In 2019, we tracked one individual from Newton County to Lawrence County, Arkansas, which resulted in the location of one maternity colony comprising two primary and five alternate roost trees. Our results confirm that Indiana bats do form maternity colonies in Arkansas, in the Mississippi Alluvial Plain ecoregion, specifically in the Black River floodplain. We anticipate the discovery of additional maternity sites within the state of Arkansas during the remaining two years of our project.

Movement Ecology of Urban Resident Black Flying Foxes

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The black flying fox, *Pteropus alecto*, is a nomadic species found throughout northern and eastern coastal Australia. Habitat destruction and urbanization have decreased native winter flowering habitat causing nomadic populations to fission into residential colonies in urban areas. To better understand the ecology of resident flying foxes and the possible impacts their movements have on the transmission of disease, targeted studies are needed to examine the movement ecology of *P. alecto*. Our study aims to characterize the movement ecology of winter foraging in two urban resident colonies for later comparison with nomadic colonies at this same time of year. We hypothesize that limited food supply during winter causes resident populations to increasingly rely on lower quality, nearby urban food resources, rather than widely spread native floral resources. In July 2019, we attached GPS-GSM trackers to 6 bats in each of two resident colonies, one highly urbanized and another adjacent to more rural habitat. We recorded 1–16 (and counting) nights of tracking data per bat, allowing comparison of foraging habitats, movement patterns, and variation in nightly foraging activities. Movement ecology of resident individuals is particularly important to understand given the human-wildlife conflict in these urban camps. Furthermore, *P. alecto* is the reservoir host for Hendra virus, therefore, understanding the movement ecology of resident camps is important for understanding disease spillover. Results of our study will contribute to the development of better public communication and ecological interventions, in an effort to break the vicious cycle of human-wildlife conflict in this system.

Sex Ratios of Big Brown Bats in Michigan over a 10-year Period

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For various reasons, many mammals have disproportionate sex ratios. In 1980, Kurta and Matson (American Midland Naturalist, 104:367–369) indicated that males dominated in a sample of 362 big brown bats (*Eptesicus fuscus*) examined for rabies in Michigan, between 1975 and 1978, and suggested that males live longer than females. The number of animals tested each year has greatly increased since that time, and we reexamined sex ratios in this species, based on more than 14,000 bats that were submitted between 2008 and 2018. The proportion of males (62%) did not differ among the 10 years and was statistically identical to the ratio indicated by Kurta and Matson. The sex ratio did not differ among animals beginning hibernation, in October and November (52% male); in mid-hibernation, from December through February (56%); and those ending hibernation, in March and April (55%), suggesting that the sexes survive hibernation equally well. However, the percentage of males examined during May and June, when most females are pregnant or lactating, was 70%, suggesting a negative effect on the survival of females connected with the rigors of reproduction. Sex ratio of juveniles taken in June or July, when most were non-volant, was equal to the ratio in early August, when all juveniles were flying, indicating that survival from birth to independence is similar between the sexes. Overall, 49% of juveniles were male, which did not differ from the expected 50%.

Labs without Borders: Methods for Extracting, Amplifying, and Sequencing in the Field

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Genomic methods have revolutionized current understanding of the evolution and ecology of bats worldwide. At the same time, air travel restrictions and concerns about emerging diseases have made transporting bat tissues an increasingly expensive and fraught pursuit. To both overcome these restrictions and build capacity in high biodiversity countries, we implemented field-based molecular protocols. First, we sequenced the prokaryotic microbiome of multiple individuals in the field using a standard centrifuge, mini-PCR and mini-gel rigs, and a MinIon sequencer. Modifications to lab protocols included: 1) centrifugation steps robust at high- or mini-centrifuge speed, 2) extending proteinase-K incubation at ambient temperature and evaluating the elimination of ethanol in clean-up during extraction, 3) using lyophilized mastermix in amplification, and 4) eluting in molecular-grade water in library prep. The lack of a high-sensitivity method for quantifying DNA, however, limited the efficiency of multiplexing and reduced the life of the cell in sequencing. Second, we generated mtDNA barcodes using a cheaper, hybrid approach of extracting and amplifying in the field, with subsequent lab-based Sanger sequencing. We added a temperature control ceramic mug and Qubit fluorometer to the kit. By modifying standard procedures, and substituting some equipment with modestly priced consumer products (e.g., the mug), our protocols make critical steps in molecular genetics field-accessible, and open possibilities for future research on genomics, transcriptomics, and disease surveillance in bats.

Testing for Signatures of Dietary Switches in the 'Vision' Genes of Neotropical Bats

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Bats are well known for their highly evolved hearing and echolocation. In contrast, vision in bats has been largely overlooked. Recent molecular research has begun to readdress this balance and suggests that differing visual capabilities may relate to echolocation, diet, and roost preference across species. However, these inferences are largely based on studies of the three main visual opsins involved in color and dim-light vision. Therefore, little is known about the wider molecular adaptations of bats' visual systems and how these may relate to different dietary specializations. To study this, we used the model system of the neotropical Noctilionoidea superfamily, which comprises ~200 species, and represents an extreme example of mammalian adaptive radiation. Noctilionoids have highly divergent sensory systems, contrasting feeding ecologies (e.g., insects, fruit, and blood), and diversity in the gross morphology of the eye suggests varying reliance on vision across the clade. In order to test for genetic evidence of this, we obtained eye transcriptomes of ~40 species and screened these for the presence of molecular adaptations (i.e., positive and diversifying selection) in key branches associated with changes in diet (e.g., from insect feeding to plant-visiting). Our results revealed that molecular adaptations of vision-related genes have occurred at several key points in noctilionoid evolution, and suggests specific parts of the visual system may be under selection in particular plant-visiting clades.

Prescribed Fire Effects on Summer Habitat Use by Bats in the Cumberland Plateau

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Forests of the Cumberland Plateau and Appalachian Mountains of Tennessee and Kentucky are often managed with prescribed fire. Several declining bat species such as the federally protected *Myotis sodalis* and *Myotis septentrionalis*, as well as *Myotis lucifugus* and *Perimyotis subflavus*, use habitat within these forests. While many studies suggest that prescribed fire improves foraging habitat for bats, more information is needed regarding effects of time since last burn and fire severity on the summer foraging ecology of these bats. Our objective was to determine how activity of bats in Big South Fork National River and Recreation Area in Tennessee and Kentucky was affected by time since last burn and fire severity. From May–August 2018 and 2019 we collected bat activity data using Anabat SD2 detectors in 65 prescribed fire sites for 2–3 nights each with varying combinations of time since last burn (0–2, 3–4, 5–7, and ≥8 years), and burn severity (medium or low). *Myotis* bats were more active in medium severity burn sites than low severity burn sites, whereas *Perimyotis subflavus* were recorded in both low and medium severity burn sites. *Lasiurus borealis* were more active in medium severity sites than low severity sites, whereas activity of *Eptesicus fuscus, Lasionycteris noctivagans*, and *Nycticeius humeralis* was not affected by time since last burn or burn severity. Our findings suggest that burn severity may influence bat species composition and activity in the study sites whereas time since last burn appears to have minimal impact.

Estimation of Temporal Trends in Bat Abundance from Mortality Data Collected at Wind Turbines

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Bats experience mortality at wind turbines throughout the world, but the population level effects of this mortality have only been estimated for a single species. In this study, we leveraged a large dataset of standardized bat carcass searches at 699 turbines in southern Ontario, Canada, which were corrected for surveyor efficiency and scavenger removal. Using Bayesian hierarchical models, we tested the hypothesis that abundance of five species of bats has changed over time, controlling for the effects of mitigation at some operations. We explored whether spatial predictors including landscape features associated with bat habitat (such as wetlands, croplands and forested lands) predicted the number of mortalities for each species. We also directly tested the effects of mitigation (increasing turbine cut-in speed from 3.5 to 5.5 m/s) on mortality of each species. Our results suggest a 90–95% probability of rapid declines in the abundance of four bat species in our study area over seven years. The estimated declines were independent of the effects of mitigation, which significantly reduced bat mortality. We observed seasonal variation in spatial predictors of mortality at wind turbines, but woodlot cover consistently predicted late-summer mortality of hoary, red, and silver-haired bats, while mortality of big brown bats was highest at lower elevations. These landscape predictors of bat mortality can inform the siting of future wind energy operations. Nevertheless, our most important result is that bat abundance in the airspace appears to be declining rapidly, despite the effectiveness of mitigation in reducing bat mortality at turbines.

The Case of the Shrinking Bats: Signatures of Nutritional Stress Implicate Changing Prey Availability and Climate

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Many avian aerial insectivores in North America are in decline. These declines are attributed in part to reduced food availability, which could also affect insectivorous bats. To test the hypothesis that nutritional stress is impacting mammalian aerial insectivores, we analyzed 14 years of morphometric data from 3,759 individual little brown bats (*Myotis lucifugus*) captured at 10 maternity colonies in Yukon, Canada. We explored temporal trends in bat size with linear mixed-effects models, using forearm long-bone length at maturity (FA) as a proxy for relative access to nutrition during development, and mass as a proxy for access to nutrition in the period preceding capture. Average adult female FA length declined by 0.04 mm/year (P <0.001), and mass decreased by ~0.09 g/year (P <0.001) when controlling for Julian Day. Average adult female mass declined most steeply during pregnancy (0.012 g/year) suggesting a potential decline in the frequency of reproduction. Mass also declined with increased amount and frequency of precipitation in the period preceding capture (P <0.001). Taken together, our results reveal markers of nutritional stress in insectivorous bats and potential demographic consequences. Increasing precipitation may limit foraging opportunities for reproductive females, and further research should investigate potential declines in prey availability. A follow-up study at a larger geographic scale is in progress to clarify how widespread the observed trends might be across North America.

Phylogeographic Analysis Reveals Mito-nuclear Discordance in *Dasypterus intermedius*

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Northern yellow bats (*Dasypterus intermedius*) are tree-roosting bats in the family Vespertilionidae comprised of two subspecies: *D. intermedius intermedius* and *D. intermedius floridanus* distributed in North and Central America. The two subspecies lineages are thought to be geographically separated but this has never been tested with a molecular approach. In this study, mitochondrial sequence data from 38 *D. intermedius* and nuclear microsatellite data from 92 *D. intermedius* (across 8 loci) from across their range were used to test the hypothesis that genetically defined groups will correspond geographically with the two morphologically-defined subspecies. Though high levels of divergence of the mitochondrial sequence (11.6%) resulted in clusters that corresponded to geographic origin, no genetic structure in the population based on nuclear markers was recovered. This study suggests that *D. intermedius* has a single continuous population with gene flow between the two subspecies and relatively high genetic diversity levels (H_0 = 0.621) possibly the result of isolation and secondary contact.

Flexibility of Prey Size Selection in Sympatric Forest Bats (*Myotis*) Facilitates Dietary Overlap

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Temperate insectivorous bats are generalist predators, taking a selectively opportunistic approach to foraging that allows them to exploit spatially or temporally patchy prey. *Myotis sodalis* and *M. septentrionalis* co-occur in forests across the midwestern USA, both aerially hawking and gleaning during prey pursuit. Both consume from 14 taxonomic orders, suggesting that prey selection is conserved in these

sister *Myotis*. How do they avoid competition for food? We used DNA metabarcoding to compare prey richness and dietary overlap between 78 *M. sodalis* and 88 *M. septentrionalis* at a contiguous managed forest and riparian-wetland site in central Indiana during the 2014–2017 maternity seasons. We extend the status quo in molecular dietary analysis to redefine operational taxonomic units in terms of taxa-size classes to align our analyses with bat perceptions of prey. We found greater dietary overlap across species within sites (O_{jk} = 0.82–0.85) than within species across sites (O_{jk} = 0.71–0.77) and confirmed that both species eat what is most available—small moths, flies, and beetles (≤8–9 mm). However, both occasionally took larger prey (15–30 mm). *M. septentrionalis* took larger prey on average (9.9 v. 8.9 mm, P <0.001) and *M. sodalis* consumed a greater richness (n = 547 v. 453 taxa). *M. sodalis* took small aquatic flies more often than *M. septentrionalis*. Subtle differences in prey frequency and sizes suggest that these sister *Myotis* may eat certain insect types at different rates and could use contrasting spatial strategies to find ephemeral or larger prey.

Systematic Review of the Roost-site Characteristics of North American Forest Bats: Implications for Conservation

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Continued declines in North American bat populations can be largely attributed to habitat loss, disease, and wind turbines. These declines can be partially mitigated through actions that boost reproductive success; therefore, management aimed at promoting availability of high-quality roosting habitat is an important conservation goal. Roost-site selection in bats has been well-studied for some species, particularly *Myotis sodalis* and *M. septentrionalis*, which have existing federal protections. If co-occurring species share similar roost-site preferences, then they may benefit from forest management practices targeting *M. sodalis* and *M. septentrionalis* conservation. We conducted a systematic review of the roost-site characteristics of 13 species inhabiting eastern temperate forests to: 1) synthesize existing knowledge across species; and 2) identify potential niche overlap in roost-site preferences among species. Of 95 included studies, 44 were focused on either *M. sodalis* or *M. septentrionalis*; in contrast, only six studies described roost trees used by *Lasiurus intermedius* or *L. seminolus.* We performed multivariate ordination techniques to group species based on the seven most-reported roost-site characteristics, including tree species, diameter at breast height (dbh), tree health, roost structure (e.g., in a cavity), tree height, canopy closure, and roost height. Species examined fell into three roosting guilds: 1) southern cavity specialists; 2) foliage roosting bats; and 3) dead tree generalists. Niche overlap with *M. sodalis* and *M. septentrionalis* was significant for four species, with species selecting roosts of similar dbh (26–40 cm), canopy closure (42–70%), and tree health, highlighting their potential as conservation umbrellas in forest management.

Ecosystem Disservices: Have We Overlooked Beneficial Insects in Ecosystem Service Valuations?

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Interest in ecosystem services provided by bats has resulted in a focus on pest insects. However, pest insects are only a fraction of bats' diets. A comprehensive understanding of bats' economic and societal impact will benefit from incorporating all insect taxa consumed. Here, I examine the full suite of insects eaten by bats in the context of the insects' relationship with humans by compiling next generation sequencing data from published papers. As possible, I classified each insect taxa as pest, beneficial, or neutral, and assigned each a functional role such as pollinator, predator, or disease vector. This analysis could reveal consumption of pest insects that have not yet been economically evaluated, or indicate that the benefits of consuming some insects may extend farther than previously thought. On the other hand, beneficial insects in the diet of bats suggest an ecosystem disservice. Regardless, this analysis will provide

a broad assessment of the diet from the perspective of ecosystem services that will broaden our knowledge of these predator-prey interactions and their implications for human systems.

Testing the Protein-for-Water Hypothesis: Does Dehydration Cause an Increased Reliance on Protein Catabolism in *Eptesicus fuscus*?

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White-nose syndrome (WNS) augments water loss in hibernating bats, and dehydration plays a role in WNS-associated mortality. Some bats (e.g. *Eptesicus fuscus*), however, are resistant/tolerant of the disease and show no indications of dehydration following disease progression. While fat is the primary fuel for hibernation, the breakdown of protein yields five times more water than fat. Protein catabolism could, therefore, help WNS-resistant/tolerant bats reduce water requirements during hibernation. We hypothesized that a negative water balance influences the metabolic fuel mixture of *E. fuscus* during hibernation. To test this hypothesis, we hibernated bats in dry (~50% relative humidity) and humid (98% relative humidity) conditions at 8°C for 110 days (n = 10 per treatment) and used quantitative magnetic resonance, blood sampling, and infrared video monitoring to address our predictions. We predicted that if *E. fuscus* offset water loss under dehydrating conditions through increased protein catabolism, then compared to bats hibernating in humid conditions, they would: 1) have higher rates of protein (lean mass) loss and endogenous water production; 2) have an elevated plasma urea concentration, but a similar level of plasma osmolality; and 3) not differ in drinking frequency. We found no difference in rate of protein loss, nor endogenous water production. However, bats hibernating in dry conditions drank 52% more frequently than bats in humid conditions. Our results demonstrate that, at least in an environment with adequate drinking water, hibernating *E. fuscus* do not rely on the protein catabolism to maintain water balance under dehydrating conditions, but rather modulate water losses behaviorally.

Temporal Processing of FM Sweeps in the Auditory Midbrain of *Eptesicus fuscus*

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Most echolocating bats emit downward frequency modulated (FM) sweeps for orientation, communication, and prey detection. We studied how the auditory midbrain encodes FM sweeps by recording responses of so-called "FM duration-tuned neurons (DTNs)" from the inferior colliculus of the big brown bat (*Eptesicus fuscus*). The spiking responses of DTNs are selective for stimulus duration. We examined how "FM DTNs" encoded two temporal properties of FM sweeps: signal duration and rate of FM. Using single-unit (extracellular) recording, we measured best FM tuning parameters by presenting midbrain neurons with linear FM sweeps varied in center frequency and FM bandwidth. With these best parameters, we next stimulated cells with FM sweeps randomly varied in duration and measured their best duration and temporal bandwidth of duration tuning at +10 dB above threshold. To separate FM duration-tuning from FM rate-tuning, we doubled (and then halved) the best FM bandwidth while keeping the center frequency constant, and then re-measured each cell's temporal bandwidth of duration tuning using bandwidth-manipulated FM signals. If a cell was "FM duration-tuned", then its range of excitatory FM durations should remain constant despite changes in signal bandwidth; however, if a cell was "FM rate-tuned", then its range of excitatory FM durations should vary predictably and correspond to similar FM sweep rates. The overwhelming majority of neurons we tested with bandwidth-manipulated signals were FM rate-tuned and not FM duration-tuned. We conclude that the dominant temporal parameter for FM tuning in the inferior colliculus of the bat is FM sweep rate.

The Humerus Nature of the Femur

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Similar to the adaptive nature of the humerus for flight in bats, the proximal end of the femur shows adaptive diversity, a phenomenon hypothetically related to a combination of phylogenetic constraints and function (e.g., hanging, use of the uropatagium, quadrupedal locomotion, and flight). The spatial and functional relationships between the fulcrum (ball of the femur or femoral head), input levers (greater and lesser trochanters), and output lever (femoral shaft) require in-depth analysis in order to understand the myriad ways the hindlimbs are used in bat locomotion. We tested the hypothesis that adaptations of the femoral head and trochanters are related to both quadrupedal and flight locomotion. Preliminary results indicate that the proximal end of the femur is widely variable, showing functional divergence beyond phylogenetic constraint. We found that vespertilionid femur variation is driven by length variables, whereas phyllostomid variation is driven by angle variables, and molossids show limited variation in both. We conclude that femur variation is more related to flight rather than quadrupedal adaptations, or a combination of the two, similar to the humerus.

Preliminary Acoustic Bat Survey of the Boreal Peatlands of Central Ontario

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The boreal peatlands of central Ontario province are at or beyond the northern extent of the range of most of the eight bat species that occur in Ontario, half of which are listed as endangered species at risk. The region is underlain by granitic or gneissic bedrock, rich in potential mining resources that play an important role in the region's economy. Mining activity and other land use alternative habitats, potentially displacing native wildlife, including bats. Typical land cover at the northern extent of this ecoregion is peat shrublands, punctuated by scattered stands of coniferous and mixed forests, and dissected by small streams and rivers with densely forested riparian zones. Available habitats provide potential foraging and roosting, but not hibernation resources for bats. We conducted a preliminary acoustic bat survey of a proposed mining site in this region to characterize bat species diversity and activity in the area for an environmental impact assessment of proposed mining activity. We hypothesized that the site would be occupied primarily by long-distance migratory tree bats (*Lasiurus cinereus*, *L. borealis*, and *Lasionycteris noctivagans*), and possibly by larger-bodied, cold-tolerant cave bats, such as *Eptesicus fuscus*. We deployed two acoustic bat detectors along probable bat travel corridors (road and river) and recorded for ±20 nights. We will report on our preliminary findings and potential implications for proposed land use activities in the region.

Conserving Caves in the Caribbean for Critically Endangered Bats

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Bat species that depend on subterranean habitats and aggregate in large numbers are particularly vulnerable to threats that destroy or degrade roosts. However, caves are also focal habitats that are tractable targets for conservation. If executed effectively, cave conservation efforts can provide meaningful protections to safeguard species from extirpation. Here, we discuss recent efforts to identify and execute

conservation measures to protect two caves identified as the last remaining roost sites for two critically endangered bat species in Jamaica – the Jamaican flower bat (*Phyllonycteris aphylla*) and Jamaican funnel-eared bat (*Natalus jamaicensis*). Jamaica is the most bio-endemic island in the Caribbean and an important contributor to biodiversity in the region. Primarily due to the threat to its endemic species of bats, Jamaica is included in the International Union for the Conservation of Nature (IUCN) list of countries with the most at-risk mammals. Twenty-one species of bat are found on Jamaica; five of these species are endemic to the island, while another eight species are restricted to the Caribbean. Almost half (10/21) of the species found on Jamaica are obligate cave dwellers. Human population growth driving agricultural, industrial, and commercial expansion has resulted in intense competition for land, leading to the loss or fragmentation of many natural habitats and a reduction and loss of biodiversity. Bat Conservation International, the Jamaican Caves Organisation (JCO) and the National Environment and Planning Agency (NEPA) are collaboratively developing and executing cave conservation strategies to protect the remaining roosts of critically endangered bats in Jamaica.

Indiana Bat Presence in Sparta, IL before and after White-nose Syndrome Exposure

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The Indiana bat (*Myotis sodalis*) can be found throughout the state of Illinois. The Indiana bat has been federally listed as endangered since 1967. Due to the fact that the Indiana bat is federally endangered, the US Fish and Wildlife Service (USFWS) requires surveys to occur before habitat modifications occur, which may impact the species. Surveys are conducted via mist netting per requirement of the USFWS. Surveying began in 2002 at Sparta Training Area through the Illinois Department of Military Affairs in accordance to the guidelines of the USFWS. The netting surveys resulted in no Indiana bats being captured in 2002. The Sparta Training Area was resurveyed in 2012 and resulted in Indiana bats being captured. In 2013, white-nose syndrome (WNS) was confirmed in the state of Illinois and is currently confirmed in all counties where bat hibernacula are located. The Sparta Training Area was resurveyed in 2014 where Indiana bats were captured after the exposure of WNS to the area. The full impact that WNS has on this particular population of Indiana bats has yet to be determined but surveying efforts will continue in July of 2019.

Integrative Taxonomy Reveals Cryptic Speciation in *Trachops cirrhosus* (Chiroptera, Phyllostomidae)

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Trachops Gray, 1847 is a monotypic carnivorous bat, with only *Trachops cirrhosus* (Spix, 1823) currently recognized. Three subspecies are broadly distributed across the Neotropics and some studies have raised the hypothesis of cryptic speciation in *Trachops*. Therefore, the main goal of this study was to investigate the diversity of *Trachops* along its distribution, integrating molecular, morphometric, and ecological niche analyses, to understand potential species boundaries in the genus. Results show that *Trachops* is composed of two species: *T. ehrhardti*, monotypic, and *T. cirrhosus*, with 2 subspecies (*T. c. cirrhosus* and *T. c. coffini*). Among all the genetic lineages, the southern Atlantic Forest (*T. ehrhardti*) was the most divergent, splitting from its sister (*T. cirrhosus*) about seven million years ago. Morphometric analyses also point to the existence of two forms of *Trachops*: large or small-sized, and although *Trachops ehrhardti* from the Atlantic Forest and *T. c. coffini* from Central America are similar in size, they are morphologically distinct. *Trachops c. cirrhosus* is larger, showing clinal size variation. Ecological niche overlap tests suggested that the similarity between niches may be acting to maintain similarities in size. Additionally, niche identity tests confirmed the uniqueness of the niches for each taxon. Integrating genetic, ecologic, and morphometric data allowed us to clearly delimit *T. ehrhardti* and *T. cirrhosus*. The current

floristic differences between the southern and northern Atlantic Forest and all biotic and abiotic interactions involved may represent ecological barriers for the two species of *Trachops*.

Pit-tagging Species Impacted by White-nose Syndrome on Maternity Sites: Not So Simple

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Bats can be challenging to study, however, the development of new technology, like the Passive Integrated Transponder (PIT tag) in the 80s, facilitated projects that required individual identifications. More recently, the appearance of white-nose syndrome (WNS) in North America raised questions, such as the potential carry-over effects of the winter disease during the summer time. While PIT tag data could provide valuable information about the population dynamics of WNS-impacted species, few studies have been published yet. Our objective was to evaluate the seasonal and annual return rate of reproductive females at maternity sites with varying times since the arrival of WNS. On one site, we also captured bats during three consecutive years to evaluate pit tag loss. Between 2016 and 2019, we captured and pit tagged little brown (*Myotis lucifugus*) and northern long-eared bats (*M. septentrionalis*) on four maternity sites where WNS arrived recently (n = 2) and not recently (more than 5 years; n = 2). Manipulations included species identification, assessment of reproductive status and wing damage index, weighing, pit tagging, banding, biopsying, and *Pseudogymnoascus destructans* swabbing. Seasonal and annual return rate varied between 0%–71% and 0%–78%, respectively, with lower return rate on sites with recent WNS arrival. Average pit tag loss was 20% (n = 10). The impact of the manipulations seems to be higher on sites where WNS is recent and prevents us from evaluating population dynamic parameters. In-hand recapture was low (mean = 18%) compared to antenna detections (mean = 65%), which might be because bats remember and restrain themselves from leaving on capture nights.

Modeling Long-term Genetic Diversity of Little Brown Bat Populations after Infection by White-nose Syndrome

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The little brown bat, *Myotis lucifugus,* is one of many North American bat species showing large population declines due to white-nose syndrome (WNS), a fungal disease affecting hibernating bats. This disease has resulted in population declines of up to 99% in some colonies. However, long-term population viability studies have shown improved survival rates after WNS-related mortality events and suggest possible evolutionary rescue of *M. lucifugus* populations due to inherited WNS resistance sweeping to high frequency in affected populations. We created forward-in-time simulations based on *M. lucifugus* population parameters using the population modeling software simuPOP in order to examine the resulting change in genetic diversity of populations over time. The modeled populations were simulated to undergo population decline due to WNS mortality, followed by growth dependent on the frequency of resistant phenotypes, with parameter estimates from real WNS-infected *M. lucifugus* populations. We examined the effect of initial population size, threshold frequency of resistant phenotypes, varying growth rate after initial WNS-related mortality, and selection via evolutionary rescue. The effects of evolutionary rescue on genetic diversity at selected and unlinked neutral loci were tracked as changes in allele frequencies, heterozygosity, and effective population size in a variety of scenarios. Our results provide a forecast of the potential future impact of white-nose syndrome on genetic diversity in *M. lucifugus* populations.

Assessing the Conservation Status of North American Bats

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Assessing the conservation status of all North American bat species can be useful to mobilize support for bat conservation, and to identify priorities for conservation action. The North American Bat Conservation Alliance is assessing the status of North American bat species, using criteria similar to those recently applied by Partners in Flight to assess the status of all bird species in North and Central America or the Mexican federal government to assess all plant and animal species in Mexico. The assessment considers several criteria: population size, distribution, population trend, intrinsic vulnerability, and threats (as an indication of anticipated future population trend). Each criterion is assigned a numeric value from 1 to 5, based on a combination of quantitative data and expert judgement. Intermediate scores are assigned when information is lacking, allowing assessment of both well-known and poorly known species. The combined score gives an index of conservation concern, with higher scores representing greater concern. For threats, additional information is tracked on the specific threats affecting each species. A workshop is planned for the two days immediately prior to NASBR, using expert elicitation approaches to apply these criteria to assess the status of all species occurring in the USA and Canada. A subsequent workshop will be held in Mexico to assess the remaining species. This presentation will describe in detail the criteria and their rationale, and will summarize the outcomes of the first workshop.

The Role of Skin Temperature in the Resistance of *Myotis leibii* to White-nose Syndrome

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White-nose Syndrome (WNS) was first observed at 6 caves in central NY during 2007–08. WNS is caused by a cutaneous infection with the fungus *Pseudogymnoascus destructans* (*Pd*) during hibernation. This fungus has since spread to bat hibernation sites located in 33 U.S. states and 7 Canadian provinces. WNS leads to over-winter mortality rates as high as 98% for 4 of the 6 bats that hibernate in the northeast: *Myotis lucifugus*, *M. sodalis*, *M. septentrionalis*, and *Perimyotis subflavus*. The Eastern small-footed bat (*Myotis leibii*) may be more resistant to cutaneous infection with *Pd*, however, since the number of *M. leibii* hibernating at 42 sites has declined by only 12% since the appearance of WNS. We conducted a 3-year study on *M. leibii* hibernating in NY to test this hypothesis. The mean torpor bout duration of hibernating *M. leibii* was 25.4 $\pm$ 3.0 d, with a mean skin Temperature (Tskin) during torpor of 15.7 $\pm$ 1.1ºC. The mean Tskin maintained during torpor ranged from 12.0 to 18.8ºC between individuals, with 71% of the *M. leibii* observed maintaining a Tskin > 16.0ºC during torpor. Little brown bats (*M. lucifugus*) hibernating in the same mine during this period, however, maintained a mean Tskin during torpor of 11.5 $\pm$ 1.0ºC. The growth of *Pd* is inhibited at temperatures > 16.0ºC. Our findings thus indicate that *M. leibii* is more resistant to *Pd* growth on their skin during torpor, and thus WNS, due to a relatively higher Tskin maintained during torpor.

Mapping Resistance Landscapes and Transmission Corridors for White-nose Syndrome in Western *Myotis*

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White-nose Syndrome is an emergent disease in bats that currently threatens multiple North American species with extinction and has spread rapidly across the continent since its initial detection in New York State in 2007. The causative fungal pathogen, *Pseudogymnoascus destructans* (*Pd*), is likely endemic to Europe and Asia, where bats exhibiting growth of the fungus do not manifest the concomitant symptoms that typically lead to death in North American species. This strongly suggests that resistance in Eurasian bat species is the result of co-evolution and repeated selection by the pathogen. Further, some eastern US populations are showing signs of recovery. Effective management is therefore contingent on both identifying the genomic basis of resistance and accurately mapping resistance-associated variation across a broad geographic range and for multiple species. This will help to identify vulnerable and refugial populations as the disease continues to spread west. Additionally, high-resolution genomic data for multiple *Myotis* species can elucidate regional patterns of gene flow, which is critical to identifying transmission corridors and hence targeting areas for surveillance. However, these endeavors necessitate a high-quality reference genome for North American bat species, specifically for members of the genus *Myotis*, as these species have shown the greatest susceptibility to WNS infection. Here we present the objectives, proposed methods, and preliminary results for our study to produce a high-quality reference genome for *M. lucifugus*, elucidate genomic regions involved in resistance to WNS, map this variation in western *Myotis*, and evaluate population vulnerability in western states for multiple species.

Intraspecific Variability in the Wing Morphology of Migratory Silver-haired Bats

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Differential migration – intraspecific variation in migratory distance among individuals – is very common across taxa, including some bat species. Within differentially migrating populations of some species (e.g. some birds and insects), longer-distance migrants differ morphologically from shorter-distance migrants and/or sedentary individuals, often in ways that optimize flight efficiency. Recent stable isotope evidence suggests that silver-haired bats (*Lasionycteris noctivagans)* are differential migrants and we used stable hydrogen isotope techniques to investigate morphological correlates of variation in migratory distance in this species. We hypothesized that longer distance migrants would be better adapted to optimize flight efficiency than shorter distance migrants. We predicted that migrants with stable hydrogen isotope fur (δ^2H_{fur}) values indicative of more northern locations of summer residency would have higher wing aspect ratios, lower wing loading, and more pointed wing tips than individuals originating from a lower latitude of summer residency. We collected measurements of wing morphology and samples for δ^2H_{fur} analysis from 81 bats captured during spring migration in New Mexico. There was no relationship between δ^2H_{fur} and any of the predicted flight metrics, but a principal component analysis indicated that bats whose δ^2H_{fur} indicated they spent the summer at higher latitude or elevation locations were larger than those from lower latitudes or elevations. These findings suggest a previously undescribed cline in *L. noctivagans* size that aligns with Bergmann's Rule and has important implications for the energy budgets of larger summer residents at northern latitudes who may be engaging in cross-continental migration.

Major Threats, Challenges, and Solutions to Global Bat Conservation

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Many of the threats that bats face (e.g., habitat loss, bushmeat hunting, climate change) reflect the conservation challenges of our era. However, compared to other mammals and birds, we know significantly less about the population status of most bat species, which makes prioritizing and planning conservation actions challenging. Over a third of bat species assessed by the International Union for Conservation of Nature (IUCN) are considered threatened or data-deficient, and well over half of the species have unknown or decreasing population trends. That equals 988 species, or 80% of bats assessed by IUCN, needing conservation or research attention. Delivering conservation to bat species will require sustained efforts to assess population status and trends and address data deficiencies. Successful bat conservation must integrate research and conservation to identify stressors and their solutions and to test the efficacy of actions to stabilize or increase populations. Global and regional networks that connect researchers, conservation practitioners, and local stakeholders to share knowledge, build capacity, and prioritize and coordinate research and conservation efforts, are vital to ensuring sustainable bat populations worldwide. We will present recent efforts toward focused conservation action on critically endangered bats to showcase how targeted conservation actions are key to saving species from extinction.

The Hibernation Phenotype: Interspecific and Regional Variation of Hibernation Physiology

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Hibernation is a common strategy used by temperate bat species to cope with periods of resource limitation. Despite the commonalities of hibernation across species, the specific strategies used by hibernating bats vary with respect to latitude and regional environmental conditions. Regional adaptations of torpid metabolic rate (TMR), evaporative water loss (EWL), and accumulated fat stores are often observed. For most bat species, however, there is little information on hibernation strategies, nor has there been focused study on the influence of environmental conditions on hibernation physiology and behavior. We tested the prediction that hibernation physiology varies among species and regions. Specifically, we predicted that bats in colder, drier habitats will have lower TMR and EWL to conserve energy and water during hibernation. To test this prediction, we used dataloggers to record hibernaculum microclimate and respirometry to measure TMR and EWL from ten western bat species. We observed species-specific variation in EWL but no differences in TMR. Bats that inhabit arid regions and use unstable microclimates during hibernation had lower EWL than bats from wetter habitats that use stable hibernacula. By measuring the suite of physiological characteristics, or "hibernation phenotypes", exhibited by hibernating bats, we can develop a new framework by which to categorize the conservation needs of hibernating bats. With the increasing threats of white-nose syndrome, wind energy production, and widespread habitat loss, understanding the habitat needs of hibernating bats within a conservation physiology framework will provide valuable information for future conservation efforts.

Human-caused Disturbance and the Effect of Nature-based Tourism on Bats

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Nature-based tourism is a growing industry worldwide, with over 8 billion visitors annually to protected areas. This industry generates financial resources for protected areas, wildlife conservation, and

raises public awareness and appreciation of nature. However, tourism also places pressure on protected areas and wildlife as managers try to balance tourism with ecological conservation. Tourists and the disturbances caused by tourists can be perceived by animals as predators or predation risk. These perceived threats can affect fundamental life history processes and behaviors, ultimately decreasing the overall fitness of the animals. The nocturnal habits and unique life history traits of bats make it difficult to compare the impacts of tourism between this unique group of mammals and other taxa. The literature analyzing these impacts on bats and their habitats is very limited, leaving bats in a perilous condition without a baseline to draw proper conservation initiatives. Here, we emphasize the need for research on areas addressing topics such as behavior, ecology, and physiology, which are fundamental to understanding the unknown consequences of the growing tourism industry on bats.

Warming Up Without Dinner: Hibernating Bats without Foraging Opportunities Desynchronize from Sunset despite Warm-climate

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For hibernating bats, arousals from torpor account for up to 90% of energy budget. A previous study of bats from moderate climate found hibernating bats synchronized arousals with sunset to allow foraging opportunities on warmer nights ("Warming up for dinner" Hope and Jones 2012). In another study, bats hibernating in cold-climate with no opportunity for winter foraging, aroused randomly ("Staying cold through dinner" Czenze et al. 2013). We conducted an experiment to test which factors could lead to synchronized nocturnal arousals. We collected 98 tricolored bats (Perimyotis subflavus) from Mississippi, placed them in environmental chambers at different temperatures (5, 8, 11° C), and recorded arousals from December 2018 to March 2019. We hypothesized (1) if arousal synchrony is linked to possible winter foraging then arousals should be synchronized with nocturnal periods at warmer temperature, (2) if external cues (e.g., light, temperature cycle) are required for maintenance of circadian rhythm then arousal times should randomize over time, and (3) if endogenous factors (e.g., fat stores) drive arousal synchrony then arousal times should synchronize with nocturnal periods as fat stores decline through hibernation. We found partial support for each of our predictions. Synchrony of arousals was related to temperature (nocturnal arousals in colder temperatures), period of hibernation (nocturnal arousals in early hibernation), and body condition (synchronized arousals in lowest body weight bats late in hibernation). Combined, these results suggest the maintenance of synchronized arousals through hibernation is the result of both endogenous (energy stores) and exogenous factors (environmental conditions, external sensory cues).

Cataloguing Bat Ecological Interactions across the Globe: The Bat Eco-interactions Database

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With over 1400 species worldwide, bats are critical components to many ecosystems as pollinators, seed dispersers, and insect predators. Scientific studies of their interactions with plants and arthropods are increasing and continue to reveal the critical roles bats play in nature and the benefits they provide to human economies. We created a platform, the Bat Eco-Interactions Database (formerly the Bat-Plant Interactions Database), to catalog all published accounts of bat interactions with plants and arthropods to facilitate scientific research, reduce duplication of effort, and share and visualize published data. For each interaction we include family, genus, and species of each interactor (bat, plant, or insect); type of interaction (pollination, visitation, consumption, dispersal, transport, roost, host); details of the location (country, habitat type, elevation, GPS); and citation. Search results can be visualized in tables or geographically and are available for download. The database is open sourced, free, and updated by its users at www.batplant.org. Currently over 8000 interactions are included from Latin America, Asia, and Africa and

we are continuously adding regions and publications to the list. We invite students and researchers to become a part of this online community by submitting publications or adding data directly through the online portal.

A Pilot Study to Assess Using Pooled Guano from Summer Roosts for National *Pd* Surveillance

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Surveillance of the fungus that causes white-nose syndrome in bats, *Pseudogymnoascus destructans* (*Pd*), primarily involves collecting skin swabs or environmental substrate at underground sites during winter hibernation. However, there are regions where hibernacula are unknown or inaccessible, particularly in the western United States. Results of preliminary field and laboratory experiments indicate that analyzing pooled guano collected at above-ground summer roosts may be a promising alternative surveillance strategy for early detection of *Pd*. We conducted pilot field studies at states along the leading edge of the pathogen distribution to provide proof-of-concept prior to incorporating this strategy into national surveillance efforts. Sites that were within 200 km of the nearest *Pd* detection and that contained *Myotis* species were targeted. Fresh guano was to be collected over a four-week period starting in mid-May, shortly after bats started arriving after hibernation. No *Pd* was detected at the 15 roosts sampled in 2018, but several factors could have increased the probability for false negatives, including delayed sample collection due to difficulty identifying and accessing summer roosts that met site selection criteria, site substitution with roosts of non-target species, improper execution of collection protocol, and temporarily lost shipments. In 2019, 40 sites were targeted with stricter selection criteria and improved guidance on protocols. Results from these samples will be presented and benefits and limitations of this sample type will be discussed in the context of the national *Pd* surveillance project.

NABat on the Northern Prairie: Year 1 of State-wide Acoustic Monitoring in North Dakota

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North Dakota is in a precarious position in regards to WNS and its impacts on bats in the region. With the presence of the disease in three of the four neighboring states/provinces, plus the documentation of a WNS+ *Myotis lucifugus* in central ND in June 2019, more information is needed about the status of bat populations in the state. In Summer 2019, we launched the first statewide acoustic monitoring program for bats in ND, following the GRTS methodology of the North American Bat Monitoring Program (NABat). The goal of the project was to collect the first of many years of data in a long-term acoustic monitoring effort to assess relative changes in bat populations over time. Acoustic data was collected at 58 sites across the state from June to August 2019, with a minimum data collection of four nights per site. Echolocation call sequences were classified to species using Sonobat 4.4.1; all data and associated classifications were submitted to the NABat database. Data will: 1) be used to examine patterns of species presence/absence across the state and assess agreement with known distributions, 2) serve as a comparison point for data collected in future summers at the same sites, and 3) be compared to the results of ad hoc acoustic sampling done in a non-standardized manner across ND from 2009–2018.

Monitoring Bats to Assess White-nose Syndrome Impacts in Great Lakes National Parks

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Over the past decade, the combined threats of wind energy, climate change, and the fungal disease white-nose syndrome have prompted greater interest in bat research and conservation, including on public

lands. The National Park Service began coordinated region-wide bat acoustic monitoring in Great Lakes parks in 2015. We present data collected in the summers of 2016–2018 at nine parks located in Indiana, Michigan, Wisconsin, and Minnesota. We conducted passive acoustic sampling at over 200 sites per year, with an average of 9 nights per deployment. This resulted in over 275,000 bat echolocation call files recorded per year and detection of at least six species per park. Bat activity (call files per deployment night) decreased in 2017 and 2018 compared to 2016. As a group, hibernating species showed greater declines than migratory species. Since hibernating species are more susceptible to white-nose syndrome, our results suggest that the disease was impacting Great Lakes populations during this three-year period. Continued monitoring will help parks track the status of their bat populations and provide data to better inform management decisions.

Searching for a Silver Lining: Requesting Data for Silver-haired Bats

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To assess whether silver-haired bats exhibit regional or partial migrations, I am requesting that colleagues from across North America, particularly from latitudes within the northern United States and Canada, share data with me. The data I need include acoustic recordings during spring and fall migrations, winter acoustic recordings, and capture records during peak migration (spring and fall) and winter. Using acoustic data, I will compare the timing of spring and fall migration between silver-haired and hoary bats (long-distance migrants) and little brown bats (regional migrants). If the migration timing of silver-haired bats is similar to one or the other, it would suggest these bats one migratory strategy versus the other. Additionally, I will analyze my own winter acoustic data to determine if and where silver-haired bats are active in the winter months. Finally, I aim to compile tissue samples from across the range of silver-haired bats to explore the landscape genetics and relatedness of populations. It is my goal to collect data from North American bat researchers, across the range of silver-haired bats, to complete this large-scale project.

Seasonal Variation in Male Urinary Estradiol and Transfer to Female Conspecifics in *Eptesicus fuscus*

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Current research suggests that unconjugated steroids excreted in the urine of male mice alter the reproductive behavior 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 behavior and reproductive physiology of female bats during critical reproductive periods, as transferred steroids were found in both neural and reproductive tissues.

Foraging Behavior and Habitat-use of Female Rafinesque's Big-eared Bats on a Fragmented Landscape in Rural Arkansas

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Studies have been conducted on the foraging behavior and habitat-use of Rafinesque's big-eared bats (*Corynorhinus rafinesquii*; CORA) in different habitats types, however not much is known about their behavior on a highly-fragmented, agricultural landscape. Bottom-land hardwood forests are the main habitat type for CORA located in the Mississippi Alluvial Plain but are rapidly being converted for alternative land-use practices. The purpose of this study was to compare foraging behavior and habitat-use between lactating and post-lactating females from a barn colony during the months of July and August (2018 and 2019). The study site was a family-owned farm in Jackson County, Arkansas. In total, 24 lactating females and 13 post-lactating females were transmittered and radio-tracked. Semi-fixed, simultaneous triangulation was the method used to collect spatial data. LOAS calculated the coordinates of their locations during triangulation, and BIOTAS estimated home ranges and core foraging areas. To assess habitat-use, coarse-scale habitat assessments and land-usage maps were created in ArcGIS, and R was used for all statistical analysis. Lactating bats used the barn to roost while post-lactating bats were found more often in roost trees. A total of 15 roost trees were located between the two years. Also, lactating bats were more stationary while foraging and post-lactating were sporadic, suggesting differences in foraging behavior based on reproductive status. Many core foraging areas for both lactating and post-lactating bats occurred over agricultural fields, thus implying that our study species could play a role in controlling pests within the research site and similar habitat types.

Host and Environment Interact to Drive Colony Persistence of *Myotis lucifugus* Impacted by White-nose Syndrome

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Following the invasion of *Pseudogymnoascus destructans* into North America, white-nose syndrome (WNS) caused widespread population declines and extirpations of the little brown bat (*Myotis lucifugus*). However, some remnant colonies of *M. lucifugus* have stabilized and are now persisting despite infection prevalence remaining high. Identifying the mechanisms of persistence in these colonies is essential to the conservation of bat populations impacted by white-nose syndrome. In this study, we conducted a translocation experiment with *M. lucifugus* collected from persisting colonies to explore the relative role of the host and the hibernacula environment in driving persistence. Our data suggest that traits favorable to host survival have been positively selected for by WNS, but that environmental characteristics within hibernacula interact strongly with these traits to determine disease outcome. In the warmest and wettest site, mortality during the WNS epidemic was 100%, but in the persisting little brown bats used in this experiment, we observed only 20% mortality within the same site. However, mortality was significantly higher in this site compared to a cold and wet site, where mortality was <1%. Ultimately, our results show that the coevolutionary dynamics between hosts and pathogens following pathogen invasion can be dependent on the host's environment.

Population and Habitat Assessment of Bats in Southwest Nova Scotia Post White-nose Syndrome

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White-nose syndrome (WNS) was discovered in Nova Scotia in 2011, resulting in a >95% reduction of the resident bat populations. Prior to the onset of WNS, Kejimkujik National Park (KNP), in southwest Nova Scotia, had apparently healthy populations of *Perimyotis subflavus, Myotis lucifugus,* and *Myotis septentrionalis*. We examined the status of these populations and their respective roosting habitats in a post WNS scenario. We used mist nets to catch bats along rivers and forest trails in KNP from June to mid-August. We did not catch or detect any *M. septentrionalis* and they are likely absent from KNP. The captures/unit effort show a large reduction when compared to previous efforts made during the summers of 2003–2004 and 2007–2008. We radio tagged certain individuals and tracked them to their roosts. *P. subflavus* exhibited high roost site fidelity, roosting in clumps of *Usnea tricodea* on spruce trees in the same spatially distinct areas as prior studies. Any *M. lucifugus* found roosting within KNP, were alone, and exclusively in hardwood snags. Although maternity roosts exist in buildings within 1 km of the park boundary, we did not find any natural maternity roosts within the park. These results imply a need to further examine the severity of WNS impacts in Atlantic Canada. Understanding the population decline and subsequent recovery of bats can give insights on where to focus management efforts here, and in areas with similar climates.

Population Genetics of the Honduran White Bat in Costa Rica

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Gene flow is the main factor in the maintenance and increment of biodiversity, which can be influenced by geography likewise dispersion, connectivity between populations, and habitat fragmentation. *Ectophylla alba* is a specialist species classified as "Near Threatened", apparently feeds just on fruits of *Ficus colubrinae,* and is affected by the habitat fragmentation in its natural distribution. We used 10 microsatellite loci to evaluate the population genetic structure of the Honduran white bat (*Ectophylla alba*) in 6 localities of Costa Rica. Our results indicate medium levels of population genetic structure among sampled populations. We observed low to medium genetic diversity across most loci. Total heterozygosity for all populations was medium to low (mean HE = 0.659, mean HO = 0.672). The AMOVA showed that most of the genetic variation was within populations and was due to differences among populations, mainly due the geographic distance among them. The absence of the significant correlation between genetic and geographic distances indicated little isolation by geographic distance. Average relatedness within colony members was close to zero, did not differ significantly between the different colony types, and kinship is unlikely to be a major grouping mechanism in this species with no evolutionary evident kinship selection. The results of this study are a framework for future studies, they can also be used for the right management and conservation of this species.

Genomic Shifts Behind Dietary Diversification in Phyllostomid Bats and Genomic Signatures of Parallel Evolution in Nectar-feeders

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The New World Leaf-Nosed bats (Phyllostomids) exhibit a diverse spectrum of feeding habits and innovations in their nutrient acquisition and foraging mechanism, however, the genomic signatures associated with distinct diets are unknown. We conducted a genomic comparative analysis to study the evolutionary dynamics related to dietary diversification and specialization. We sequenced, assembled, and annotated the genomes of the Phyllostomid species: *Macrotus waterhousii* (insect-feeder), *Artibeus jamaicensis* (fruit-feeder), and the nectar-pollen feeders *Leptonycteris yerbabuenae, Leptonycteris nivalis* and *Musonycteris harrisonii*. Previously sequenced *Desmodus rotundus* was also incorporated into the analysis. Phylogenomic analysis displays differences in gene family expansion, contraction, and pseudogenization events, whereas the vampire and nectar-feeders exhibit many rapidly evolving genes. Independently of diet, genes involved on iron metabolism and food intake experienced multiple expansions. We also identified many losses and pseudogenizations in sensory genes (photoreceptors, taste and olfactory receptors) that may be relevant for feeding strategies. Moreover, we found adaptation signatures associated with specialized diets: the vampire exhibited traits associated with the complex mechanisms needed to maintain a blood diet (such as coagulation mechanisms), whereas the nectarivore lineage had a group of 14 positively selected genes involved in sugar, lipid, and iron metabolism. Interestingly, we detected for the genes: *Acetoacetyl-CoA*, *Acid-alpha glucosidase*, and *alpha-ketoglutarate,* signals of adaptative selection exclusively for the nectar-feeders Phyllostomids and Pteropodids fruit-bats. Finally, we identified eight genes with signatures of parallel evolution in this group of nectar-fruit bats. These genes may explain how these animals avoid the adverse effects of diets with high glucose content.

Sex- and Age-specific Rates of Survival for Two Northern Populations of Little Brown Bats

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Peripheral populations near the limit of a species' range often exhibit lower vital rates than central populations. Understanding how these vital rates change over time is essential for managing these potentially vulnerable populations. We used seven years (2011-2017) of mark-recapture data for 4932 individual little brown bats (*Myotis lucifugus*) from two northern populations, to test the hypothesis that demographic characteristics, such as sex and age, along with seasonal environmental factors, affect variation in annual survival of little brown bats. We used Cormack-Jolly-Seber models to account for permanent emigration from the populations and included summer and winter weather parameters as predictor variables. At both hibernacula, annual survival varied over time with both age and sex of bats, but not with either summer or winter climatic variables. At 'Abyss' males had higher average annual survival rates (0.75 ± 0.035 (standard error)) than females (0.61 ± 0.04). Survival of young-of-the-year (YOY) was higher for males (0.23 ± 0.01) than for females (0.13 ± 0.01) but was lower than adult survival. At 'St. George' adult male survival (0.67 ± 0.07) was not different from that of adult females (0.65 ± 0.07), but higher than survival for both YOY males (0.47 ± 0.13) and YOY females (0.44 ± 0.13). In general, estimates of annual survival for these populations were lower than published estimates for insectivorous bat populations at lower latitudes. Through this long-term monitoring program, we identify

females and YOY as vulnerable demographics in these populations and suggest targeted efforts to protect these groups.

Bat Fly-associated Fungi: Current Developments and a Call for Global Collaborations

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Bats serve as hosts to ectoparasitic blood-sucking bat flies, which in turn can carry Laboulbeniales fungi. This is an exciting tripartite system because it is a natural experiment replicated in two different hemispheres. Here, we summarize our main findings thus far. Molecular phylogenetic inference of the large subunit ribosomal DNA and application of species delimitation methods reveal that at least one taxon of *Arthrorhynchus*, restricted to Eastern Hemisphere bat flies, is a species complex, segregated by host genus. We are also looking at associations between parasitism and abiotic factors. We used MERRAclim variables and performed statistics to explain the distribution of *Arthrorhynchus* on bat flies across Europe. *Arthrorhynchus* occurrence and prevalence was higher in habitats with low annual mean temperature and humidity, suggesting that climatic elements can shape fungal distribution. *Gloeandromyces* fungi are associated with streblid bat flies in the Neotropics. Fieldwork in Panama and study of Latin American bat flies preserved in EtOH resulted in the description of several species and morphotypes (*formae*) of *Gloeandromyces*. Similar to *Arthrorhynchus*, we found host specialization in *Gloeandromyces* taxa as a contributor to diversity – whether ephemeral or incipient. One of the most important questions in this system concerns the effect of habitat on parasitism of bat flies by Laboulbeniales fungi. We hypothesize that habitat disturbance causes parasite prevalences to increase, in line with the "dilution effect." This can only be resolved based on large, non-biased datasets and so we call for global collaborations with bat scientists and organizations.

Weather-dependent Home Range Expansion by *Nycticeius humeralis* in an Urban Environment

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Despite the negative connotation of urban sprawl for bat populations, fragmented green spaces such as parks, cemeteries, and golf courses have the potential to provide necessary resources for bats. For example, water sources in these areas can include lakes, ponds, streams, and drainage ditches. Such water resources, however, can be ephemeral when subject to prolonged periods of high temperatures and low precipitation. Yet, recent studies reveal that bat species are potentially able to adapt by using unconventional, anthropogenic-based resources, such as residential swimming pools. Thus, for those bats utilizing urban green spaces, we hypothesized that they would expand or shift their home ranges to access swimming pools as an alternative water source in the surrounding neighborhoods. To explore this hypothesis, we conducted a telemetry study tracking resident evening bats (*Nycticeius humeralis*) caught in a local park system across their summer activity period from 2017–2019 in Fort Worth, Texas, USA. Our results supported the proposed hypothesis, demonstrating that bats expanded their home ranges from the park system into the surrounding neighborhoods when average nightly temperatures exceeded ~30°C and total weekly precipitation was <1 in. Furthermore, we observed that the home ranges increased over 4 times in size under these conditions. Thus, our study indicates that urban neighborhoods surrounding green spaces can provide important alternative resources for bats, and if managed appropriately can contribute to and encourage healthy, stable bat populations.

Ancestral Generalization was a Gateway to Rapid Dietary Divergence in Neotropical Leaf-nosed Bats

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As a prime example of adaptive radiation, Neotropical leaf-nosed bats (Phyllostomidae) are a frequent subject of macroevolutionary studies. Many of these studies focus on mechanical aspects of skull morphology relating to feeding, leaving the evolution of sensory structures understudied. We used diceCT scans of 79 specimens, representing 42 species of phyllostomids and two species of outgroups, to analyze relationships between the relative volumes of three sensory structures (olfactory bulb, orbits and cochleae) and diet. Those trends were then compared with inferred ancestral sensory states. We hypothesized frugivory and nectarivory are associated with enlarged olfactory bulbs and orbits, while animalivory is associated with enlarged cochleae. We predicted that the signature sensory profile of modern plant-eating bats emerged in the ancestral phyllostomid, but not in outgroups. We also expected shifts in the rate of evolution of sensory structure volume for olfactory and orbit size in the stenodermatine ancestor coinciding with a known shift in speciation rate. We found that frugivory is associated with larger olfactory bulbs and orbits, while nectarivory is associated with relatively smaller cochleae. The phyllostomids, regardless of diet, have similar relative proportions of sensory structures and collectively differ from outgroups. The phyllostomid ancestor had larger olfactory bulbs and orbits, but no difference in cochlea volume relative to its common ancestor with outgroups. This sensory blueprint reflects the consumption of plant matter and persists across modern phyllostomids. The enlarged olfactory bulbs and orbits of the ancestor, necessary for generalizing away from insectivory, allowed for specialization into new and diverse niches.

Bat Use of Upland Ponds within the Hardwood Forest Ecosystem of Southern Indiana

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The watershed systems of the Morgan-Monroe and Yellowwood State Forests (MMYSF) of southern Indiana are largely composed of ephemeral streams. The Indiana Department of Natural Resources (DNR) created man-made ponds within the state forests for the benefit of game species. The DNR would like to determine how these ponds are used by bat species living within state forest boundaries. During the summer months of 2018 and 2019, acoustic surveys were conducted at 27 ponds within the MMYSF boundaries to determine bat activity levels for the season. Mid forest vegetation surveys were conducted at each pond to determine vegetation density, which may limit bat accessibility to ponds based on body size morphology. These activity and vegetation density levels provided the preliminary results to show a negative correlation between high vegetation levels and bat activity. From these preliminary results, a small experiment was conducted in the summer 2019 on a subsample of five ponds with low bat activity. The subcanopy vegetation was removed to determine if lower vegetation clutter will increase overall bat activity levels. Preliminary results suggest that lower vegetation density does not increase overall bat activity.

Smart Curtailment in North America: Recent Results, Ongoing Research, and Future Challenges

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"Smart curtailment" is an approach to reducing bat fatalities at wind energy facilities that uses near real-time information to predict when bats will be active in an area and curtails turbines only when bats are known or suspected to be present and at risk. One approach to smart curtailment is referred to as Turbine Integrated Mortality Reduction ("TIMR"), which uses real-time bat acoustic and wind speed data to make curtailment decisions. A recent study conducted in Wisconsin used the TIMR smart curtailment approach to make curtailment decisions at control turbines (n = 10) versus treatment turbines (n = 10). The TIMR approach significantly reduced fatality estimates inside search plots for treatment turbines relative to control turbines for pooled species data (–84.5%) and for each of five species observed at the study site. Our group estimated that the TIMR approach would have reduced curtailment time by about 48% relative to turbines operated under a standard curtailment rule used in North America (curtailment up to 6.9 m/s). In this talk I will discuss the TIMR approach to smart curtailment and describe the first TIMR study as well as two other TIMR studies, one ongoing and one planned. These studies are designed to improve our understanding of smart curtailment approaches in different North American ecoregions and address uncertainties associated with the first TIMR study. I will then reflect on some of the future challenges confronting bat ecologists seeking to understand and implement smart curtailment approaches at wind energy facilities in North America.

Evidence of Morphological Divergence in the Minor Red Bat (*Lasiurus minor*) from Mainland Red Bats

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The *Lasiurus* species complex has presented a taxonomic challenge with morphologically indistinct species, vast and sometimes overlapping distributions, and a lack of adequate sample size in small isolated regions with rare endemic species. The Minor Red Bat, *Lasiurus minor,* is currently known from Bahamas, Hispaniola, and Puerto Rico, and was originally described from two individuals. A continuing lack of specimens has prevented quantitative analysis of divergence from other recognized Red Bat species. A recent discovery of several hundred *L. minor* remains deposited by owls in a cave in Haiti provided sufficient data for the first quantitative analysis with nearby mainland species (*L. borealis* and *L. seminolus*). Skull remains from 60 *L. minor* individuals were compared to mainland species with data collected from existing literature. Results from four linear measurements revealed some morphological distinction from males and female mainland species. The condylobasilar breadth was significantly smaller in *L. minor* than mainland Red Bats, while the post-orbital constriction was significantly larger. The breadth between the anterior of the upper first premolar and posterior of the upper third molar alveoli was broader in *L. seminolus* than in *L. minor*, while only being larger in the female sampling of *L. borealis*. The length of the palate in *L. minor* was also larger than the male *L. seminolus*, yet smaller than the female *L. borealis*. These unique morphological characteristics support the taxonomic independence of the Minor Red Bat from mainland species and opens new possibilities to help the conservation assessment of this elusive Caribbean bat.

Regional Migrations of Threatened Bat Species

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Aerial and terrestrial landscapes are becoming increasingly fragmented, potentially jeopardizing the traditional migration routes of bats. Mortality of *Myotis lucifugus* and *Eptesicus fuscus* from interactions with wind turbines is higher in Ontario than other areas in North America, and turbine-related mortalities of these species may be concentrated during these species' travel from summer maternity roosts to fall swarming sites. However, the paths they take on these journeys are unknown, limiting potential risk analyses. We used the Motus Wildlife Tracking System to track the movement of bats from maternity roosts to swarming sites in south-western Ontario. We captured 108 bats (78 *M. lucifugus* and 30 *E. fuscus*) at 6 maternity roosts between July 18–August 29, 2018 and attached coded Motus nanotags (NTQB-1, Lotek Inc.). We found that some *M. lucifugus* traveled at least 175 km from their maternity roost in early September. Some individuals traveled at least 20 km/hr and 125 km/night. In contrast, *E. fuscus* were not detected farther than 40 km from their roosts. Based on speed and travel distance, it is likely that *M. lucifugus* are taking direct routes to swarming sites. These routes overlap with multiple wind farms in south-western Ontario, suggesting that the risk of turbine encounters/mortality may be highest for *M. lucifugus* during migration. Conversely, the shorter distances travelled by *E. fuscus* may result in no increased risk of turbine encounters during migration.

Ecological Traps and Thermal Refugia Determine White-nose Syndrome Impacts and Persistence

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The introduction of novel pathogens to naive host populations is a key threat to global biodiversity. The environment is a critical modifier of disease impacts, and environmental refugia where hosts but not pathogens can survive may help maintain species in the presence of virulent pathogens. However, host preference for habitats or niches where disease impacts are high may result in ecological traps that alter host population dynamics. Here, we quantify the relationship between temperature and the invasive fungus that causes white-nose syndrome in *Myotis lucifugus* to determine whether disease can shift the thermal niche of hosts. We used field mark-recapture data and Bayesian approaches with prior information from laboratory culture experiments to assess the relationship between temperature, fungal growth, and bat survival over the timespan of white-nose syndrome invasion. We found that fungal growth rates were higher on bats that roosted in relatively warm microsites, and correspondingly, bats roosting at warm temperatures were less likely to survive the winter. At the regional scale, average bat roosting temperatures declined 1C from pre- to post-invasion, because colder hibernacula served as thermal refugia from disease impacts. However, despite extremely strong selection pressure, the majority of bats continued to roost at warm temperatures that decreased bat survival. Our results suggest that source-sink dynamics are pervasive in ecology of white-nose syndrome, and that population stability will be determined by the relative availability of thermal refugia and thermal sinks or traps.

Cryptic Connections and Spatial Segregation Drive Infection Patterns in Bats

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Understanding host interactions that lead to pathogen transmission is fundamental to predicting and controlling epidemics. While the majority of transmission often occurs within social groups, the contribution of connections that bridge groups and species to pathogen dynamics is poorly understood. These cryptic connections, which are often indirect or infrequent, provide transmission routes between disconnected individuals, and may play a key role in large-scale outbreaks that span multiple populations or species. We quantified the importance of cryptic connections and space use in disease dynamics by simultaneously characterizing social networks and tracing transmission dynamics of surrogate pathogen epidemics through eight communities of hibernating bats. We then compared these data to the invasion of the fungal pathogen that causes white-nose syndrome (WNS). We found that cryptic connections increased links between individuals and species by an order of magnitude. Individuals were connected, on average, to less than two percent of the population through direct contact, and only six percent through shared groups. However, tracing surrogate pathogen dynamics showed that each individual was connected to nearly fifteen percent of the population and revealed widespread transmission between solitarily roosting individuals and extensive among-species contacts. The importance of both direct and indirect connections in pathogen transmission were reduced by within hibernacula spatial segregation not clustering behavior. Connections estimated from surrogate pathogen epidemics, which include cryptic connections, explained four times as much variation in transmission of the fungus causing WNS as connections based solely on direct transmission.

What is a Winter? Addressing Data Deficiency in Vital Model Parameters in Overwintering Bat Models

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White-nose syndrome (WNS) has been decimating North American hibernating bat populations for over a decade. While hibernation energetics models have improved mortality predictions, spatial heterogeneities in host traits critical to survival have not been previously considered. Accordingly, in this work we create spatial models of body mass and composition for the comparatively well-studied species the little brown bat (*Myotis lucifugus*) and reassess previous definitions of the duration of winter in regard to hibernation. We complied data from published literature, public databases, local experts, and our own fieldwork to create a database of spatially defined body masses and winter duration. Using these data, we fit a series of linear models with hypothesized abiotic drivers to create distribution-wide predictions for the duration of winter and the amount of body fat available prior to the onset of hibernation. We applied these predictions within a previously developed mechanistic hibernation energetic model to create survival estimates for the *M. lucifugus* once WNS spreads through the western half of its distribution. Our results

provide an improved estimation of the duration of winter over previous *a priori* estimations, as well as the first continuous estimates of pre-hibernation body mass and fat across the species distribution. Our results suggest that western *M. lucifugus* are likely to experience population declines due to WNS. Despite this, bats were predicted to miss required fat stores by less than 10% of total estimated hibernation reserves and populations may rebound after initial losses.

Bats and Lasers: Estimating Colony Size in Roosting Bats Using Ground LiDAR and Quantitative 3D Modeling

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Accurate estimates of population size and assessment of long-term trends in endangered species are critical elements of implementing a recovery program. Conservation managers and biologists use these data to make listing decisions, develop recovery plans and criteria, and inform specific consultations. Precise colony estimation remains difficult for wildlife like bats that are highly mobile, live in large groups and are active at night.Although an increasing number of tools are available for estimating colony sizes based on emergence counts, existing survey methods for roost assessment have notable limitations – they can be invasive, inaccurate, labor-intensive, cost-prohibitive, and have low repeatability. Here we report on the development and application of an alternative method to estimate the size of cave-roosting bat colonies using Ground Based LiDAR Scanning (GBLS) technology. The associated Subtractive Volume Estimation (SVE) analytical method based on GBLS compares scans of the roost with and without the bats and derives an accurate estimate of their numbers. We scanned one mixed-species hibernaculum in Missouri that is a significant roost for the endangered Indiana bat and one, medium-sized, summer roost of the Brazilian free-tailed bat in Texas. Colony estimates derived from GBLS/SVE compare favorably to estimates derived from emergence counts and have the added benefit of providing new information about the arrangement of bats and utilization of the roost. The resulting tool provides a promising and effective alternative to historic methods for deriving colony size estimates and has potential for broader application in other model systems like birds, butterflies and even historic preservation.

Eastern Small-footed Myotis Roosting Habitat on the Niagara Escarpment

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Rocky habitats are abundant in Ontario, primarily in the form of granite rock barrens and limestone cliffs and talus of the Niagara Escarpment. Despite this, there have been few records of eastern small-footed myotis (*Myotis leibii*) in the province, and only one known active maternity colony, located in a building. In 2017, we carried out a study to improve our understanding of both the distribution and roosting habits of this species on the Niagara Escarpment in Ontario. Mist-netting was undertaken directly in open or semi-open talus habitats, or on forest trails near open talus between late May and September 2017. We tracked six eastern small-footed myotis, including one lactating female, to roosts found primarily in crevices in cliffs adjacent to the capture locations. One juvenile male was also confirmed to roost in the crevice of a large talus boulder in August. We also conducted 37.5 hours of ground-based visual searches of accessible rock habitats at each study site and nearby roadside rock-cuts. Visual searches were ineffective at identifying roosts for any species of bat. Our results confirm that cliff crevices of the Niagara Escarpment provide roosting habitat for adult and juvenile Eastern Small-footed Myotis, including maternity roosting habitat. They also suggest that visual searches are not an effective way to identify roosts of Eastern Small-footed Myotis within the cliff and talus habitats of the Niagara Escarpment.

Little Brown Bats Responding to and Rebounding from White-nose Syndrome

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White-nose syndrome (WNS) has now been impacting hibernating bat populations in the northeastern United States for over a decade. Little brown bats (*Myotis lucifugus*) are one of the hardest hit species, but the population has recently shown signs of stabilization. Using a mark-recapture design, we seek to determine the status and future of the little brown bat population in the region. In addition, we are examining the impacts of WNS on the life-history of little brown bats. From 2016–2019, over 2,500 bats were captured at maternity colonies in New Hampshire, Vermont, and Massachusetts, approximately 20% of which were recaptures. All were banded while a subset of bats at two colonies were also PIT-tagged. PIT tag and band recapture data show individuals surviving WNS and reproducing over multiple years as well as bats banded as juveniles surviving and returning to their natal colonies. In addition, emergence counts conducted in the field and from infrared video suggest stable to increasing colony sizes. Wing-damage, fungal prevalence (of the causative agent of WNS, *Pseudogymnoascus destructans*), and reproductive data suggest that the effects of WNS linger into the early summer, impacting the rate and timing of reproduction with potential consequences for juvenile survival. Comparisons to pre-WNS data from New Hampshire suggest possible shifts in life-history strategies, with little brown bats beginning to reproduce at an earlier age. The results of this study will ultimately be used to inform and develop conservation strategies to promote reproduction, survival, and recovery of little brown bats.

Kootenay Community Bat Project: A Community-based Program Supporting Regional Bat Conservation in British Columbia, Canada

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The Kootenay Community Bat Project (KCBP) is a 15-year, community-based bat conservation program located in the Kootenay region of southeastern British Columbia, Canada. KCBP goals include: engaging with and supporting landowners to promote the conservation and enhancement of roost sites, increasing education and awareness around bats, their habitat and threats, and establishing permanent roost monitoring sites to gather baseline population size information. Roosts were identified through direct landowner reports (phone, email), indirect reports (neighbours, pest control), or suspected roost site investigations by KCBP biologists. KCBP developed a 'Bat Ambassador' program training community members in facilitating various types of bat workshops and educators to deliver school programs. In 2005, the "Annual Backyard Bat Count" was initiated as an attempt to document bat populations over time using citizen-science and evolved into the BC Annual Bat Count in 2012. Eight bat species were detected in roost structures, of which the *Myotis* genus was detected most often. Over 700 roost sites were identified, of which maternity roosts were detected most frequently. In general, bat roosts were detected most often in human-occupied buildings, particularly in the upper portions of the structures (roof, attic, chimney). KCBP has offered hundreds of education and outreach events including community presentations, school programs, public mist-netting nights, bat house building workshops, and targeted outreach to pest control professionals, roofers, builders, and realtors. In 2019, between 2–4 counts were conducted at >25 sites throughout the Kootenay region by engaged citizens. Future directions and lessons learned from this long-standing project will be shared.

Winter Foraging Activity of Two Cave-hibernating Bat Species in Tennessee

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During winter in the southeastern U.S., individuals of cave hibernating bat species susceptible to white-nose syndrome (WNS) will often arouse from torpor. During arousals, some individuals may leave hibernacula to forage on the landscape. We deployed VHF radio transmitters on individuals of two bat species (*Myotis grisescens* [n = 8] and *M. leibii* [n = 2]) captured outside cave hibernacula during winter and used aerial radio telemetry to explore their foraging activity. Bats were tracked from release at the hibernacula until their transmitter signal was lost or they remained stationary for $\geq$15 mins. To understand which landscape features influence foraging area selection, we mapped foraging points in ArcGIS and compared them to random points using Welch's t-tests. *Myotis leibii* were tracked 1.20 $\pm$ 0.32 km and *M. grisescens* 4.14 $\pm$ 0.58 km from hibernacula. Both species selected to forage along streams ($P \leq 0.01$), with all foraging points located within 0.57 km of water features. *Myotis leibii* also selected to forage along roads ($P < 0.01$). Management for these important landscape features, particularly streams, may benefit *M. leibii* and *M. grisescens* populations, especially during winter when prey resources are low and bats are stressed by the rigors of hibernation and WNS. Similar data collection is recommended for other bat species affected by WNS that have seen high over-winter mortality.

Winter Torpor and Arousal Activity of Four Cave-hibernating Bat Species in the Southeastern United States

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In the southeastern U.S., bats susceptible to white-nose syndrome (WNS) frequently arouse from torpor during winter and are often active outside hibernacula. We investigated the torpor and arousal activity of four WNS affected species, two with relatively low (*Myotis grisescens*, and *M. leibii*) and two with relatively high (*M. sodalis* and *Perimyotis subflavus*) WNS susceptibility. We deployed temperature-sensitive radio-transmitters on bats captured outside cave hibernacula during winter to monitor torpor and arousal profiles (n = 21) and recorded activity of others at cave entrances by implanting them with passive integrated transponder (PIT) tags (n = 1,349). *Myoits leibii* had a higher torpor skin temperature (18.57 $\pm$ 0.20 °C) than *M. grisescens* (13.72 $\pm$ 0.60 °C) and *P. subflavus* (14.62 ± 0.49 °C*;* $P < 0.048$). *Myotis leibii* also had a higher arousal skin temperature (32.29 $\pm$ 0.67 °C) than *M. grisescens* (29.01 $\pm$ 0.64 °C) and *M. sodalis* (28.59 ± 0.38 °C; $P \leq 0.016$). *Myotis leibii* had the highest activity frequency throughout the hibernation period (November–February), with 74.22 + 10.62% of tagged individuals detected at cave entrances each month compared to <30% of tagged individuals from other focal species. Of the 531 PIT-tagged bats active during winter, only 12.60% (n = 67), the majority of which were *M. leibii*, were detected at a cave entrance more than once/night. For this species, the time between detections in the same night was 0.87 $\pm$ 0.09 hrs. Understanding these differences in torpor and arousal activity will help inform WNS management strategies.

Agave Flower Visitation by Pallid Bats in the Big Bend Region of Texas

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Pallid bats, *Antrozous pallidus,* though primarily gleaning predators, are known to consume nectar of cardón cacti, *Pachycereus pringlei*, and act as effective pollinators of this species in the Sonoran Desert. It is unknown whether a similar nectar feeding behavior may be occurring in the Chihuahuan Desert of southwest Texas, where several researchers have captured pallid bats covered in pollen. We collected pollen

samples from pallid bats in Brewster County, Texas each month between April and August 2018. A total of 77 pallid bats were captured. Clear tape was used to collect pollen density samples from 67 pallid bats and fuchsin gel cubes were used to collect samples for pollen identification from 60 pallid bats. Of the 67 bats sampled with tape, 56 had substantial pollen densities on their wings. Pollen-covered pallid bats were captured in every month sampled; however, mean pollen densities in June were significantly lower than pollen densities in April and July. The pollen collected in all samples was identified as *Agave* pollen. Two *Agave* species occur in this region of Texas, *Agave havardiana* and *Agave lechuguilla*. A linear discriminant analysis (LDA) was used to distinguish pollen of *A. havardiana* and *A. lechuguilla* using measurements from reference collection pollen. The LDA classified 701 of 723 of the pollen grains as *A. lechuguilla* based on posterior probabilities of >0.5. Additional evidence from infrared video footage collected in August of 2018, indicates that pallid bats are becoming covered in *A. lechuguilla* pollen as a result of nectarivory.

Hidden in Plain Sight: Using Geometric Morphometrics on CT Scanned Bat Specimens from Open Access Repositories

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Bats (order Chiroptera) are a diverse group of mammals of which over 1300 species have been described. Traditional methods of measurement involve the use of dry skulls, a procedure that substantially increases the variance in measurements across users. Recent advances in CT (Computerized Tomography) technology have provided us with the ability to analyze wet museum specimens and thus better understand the internal structures of bats. This study is an ongoing project that highlights the use of geometric morphometrics on high resolution micro CT scanned specimens that have been previously deposited in open access repositories such as Morphosource. By describing craniofacial landmarks and semi-landmarks, inferences can be made about the size and skull shape of bats and predictions can be made about diet. Moreover, the precision involved with high resolution micro CT scanned data makes these measurements replicable and reproducible. The landmarks and semi-landmarks will be placed using the geomorph package in R and analyzed with Procrustes superimposition methods. Furthermore, this can be used as a template to study other species of mammals that have been collected and deposited in open access repositories.

Are Statistical Models Useful for Predicting Energy Budgets of Hibernating Bats?

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Regulating energy expenditure during hibernation is critical for survival in temperate bats. Multiple models have been proposed to estimate fat and mass loss during hibernation based on biophysical models and a classical understanding of hibernation dynamics. These models have provided invaluable insights into hibernation biology, but are impossible to parameterize for all but the best-studied species. Here, we aim to determine if data on skin temperatures, which are easily collected in wild populations, can be used to estimate body mass and fat loss using statistical models instead of biophysical models. We performed a captive hibernation study using 98 wild-caught tri-colored bats, *Perimyotis subflavus*. We attached temperature dataloggers to bats and maintained them in temperature and humidity controlled environmental chambers for 87 days. We measured body mass and body composition at the start and end of hibernation. We transformed skin temperature data using nonlinear multipliers and calculated the area under the curve for each bat with the goal of maximizing the amount of variation in body and fat mass lost over the hibernation period that can be accounted for by simple regression models. Based on body mass alone, our best model accounts for ~40% of variation observed. We are finalizing body composition data, which will provide higher resolution than simple body mass and should increase our descriptive power. This modelling

approach represents the first such statistical model, and we hope such techniques can ultimately be more widely applied than biophysical models and thus prove useful for management and conservation questions.

Flexible Foraging Behavior in the Hawaiian Hoary Bat

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The foraging ecology of the Hawaiian hoary bat, an endangered species, has been poorly characterized and lack of information is hampering efforts to develop effective recovery plans. We used long-term acoustic monitoring to determine habitat preferences and radio-telemetry to determine core use areas (CUA) through a kernel analysis at 50% and 95%. We used the Generalized Random Tesselation Stratified survey design to select acoustic sampling sites across nine habitat types covering a ~30,000 hectare (ha) study area. Calls were recorded for three nights in each habitat and rotated five times (round) every other month for five months for a total of 223 deployments. We applied generalized linear mixed effects models with the package glmmPQL to account for over-dispersed count data and used a negative binomial distribution with a log link. Bat activity (bat calls per minute) was highest in gulches, low-intensity developed habitats, and grasslands and lowest in forested habitats; this contrasts to data from Hawai‘i Island suggesting bats are tightly associated with mature forest habitat. We also outfitted 16 bats with radio-transmitters to characterize their foraging ranges. Mean CUA was 3,700 ha on Maui; this contrasts with 25.5 ha on the Hawai‘i Island.Our data suggest the bat prefers foraging in different habitats on Maui than bats on Hawai‘i Island and at 50% kernel has a mean CUA of over 100 times the size of the mean CUA for bats on the Hawai‘i Island. Our data suggest foraging flexibility in the species and have substantial implications for management decisions.

Can UV Lights Be Used to Create Foraging Patches for Bats in the Wake of White-nose Syndrome?

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Bats with higher fat stores are more likely to survive the winter when infected with *Pseudogymnoascus destructans (Pd)*, the fungal pathogen that causes white-nose syndrome (WNS). We explore the use of ultraviolet (UV) lights to create foraging patches of night-flying insects for bats during the pre-hibernation fattening period. We selected the Upper Peninsula of Michigan for this study because of the presence of remnant populations of*Myotis lucifugus*persisting several years after invasion of*Pd*and mortality from WNS. UV lights were deployed at 5 mine sites used as hibernaculum, lights at each sited were turned on every other night, to determine whether insect prey were attracted and bats foraging rates were higher at lights. We quantified bat foraging activity using bat detectors and infrared cameras, and insect biomass using light and malaise traps. Results will inform novel management approaches focused on helping bats survive the impacts of WNS.

Infection Patterns of *Pseudogymnoascus destructans* in Male and Female Bats

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Understanding the role of infectious diseases in shaping animal populations is crucial as increased anthropogenic movement supports new pathogen invasions, as exemplified by the introduction of the fungal pathogen *Pseudogymnoascus destructans* (*Pd*) that causes white-nose syndrome (WNS). The negative effects of WNS are evident among cave-dwelling bats as mortality occurs during the winter hibernation period, when host physiological functions become disrupted by fungal growth. We hypothesized that *Pd*

infection might vary between male and female bats given their different patterns of contact and arousal behavior. We sampled bats at 25 hibernacula across the northeast and midwest to quantify infection prevalence and intensity (i.e., fungal loads), and used generalized linear mixed models to assess differential patterns of infection by sex. We found that females were significantly more likely to be infected and had higher fungal loads than males. Previous research has found that female bats have 22% shorter torpor arousal bouts compared to males, which could limit their opportunity to remain euthermic long enough to inhibit infection. Although male bats may have more frequent contacts during mating, our results suggest that differences in torpor ecology are likely more important than sex-based differences in contacts. Female bats may suffer higher direct mortality as a result of higher fungal infections, and there is potential for WNS to have cascading effects on bat reproduction. These effects could reduce overall recruitment, resulting in Allee effects on bat populations, thus extending the effects of WNS beyond the hibernation season.

Bat Responses to Nocturnal Insect Light-traps in Eastern Iowa

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There are nine species of insectivorous bats (Chiroptera: Vespertilionidae) recorded for Iowa that consume both human-disease vectors and agricultural pests. These bats are crucial components to healthy forest ecosystems and human economies. This project sought to determine whether using insect light-traps to attract insects would in turn serve to attract bats. This could enhance opportunities to capture bats for research. Our Null hypotheses are no differences in bat community structure (measured as both species diversity and abundance) at light-trap sites versus control sites. To evaluate the impact of light-traps on bat activity, SM3Bat detectors (Wildlife Acoustics, Inc.) were deployed at multiple locations within Dubuque County, Iowa. At each location, likely bat travel corridors associated with water sources were identified. Bat detectors were deployed at each site at least 100-meters apart; one associated with an operating light-trap while the other was associated with a non-operating light-trap. Data files were analyzed by Kaleidoscope Pro software, which provides species-specific identification for bat calls with sufficient data. Preliminary results suggest that total bat calls per night at sites with insect light-traps is greater than at sites without light-traps. More specifically, *Myotis lucifugus*, which was the most abundant species as measured by bat calls, were the main drivers of the overall results as they appeared to respond more strongly than other species at sites where light-traps were deployed when compared to sites without light-traps. Initial data analysis implies that light-traps do have an impact on bat activity and community structure.

Predator-prey Kinematics of a Specialized Population of Swainson's Hawks and Brazilian Free-tailed Bats

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Predators and prey often exhibit coupled dynamics, especially during pursuit and evasion. These interactions require the coordination of complex sensorimotor control on rapid timescales, with a high potential cost for prey. Many predators and prey have co-evolved over time, resulting in an evolutionary arms race that can influence morphology and behavior. In this study, we investigate the pursuit and evasion strategies, respectively, of Swainson's hawks (*Buteo swainsoni*) and Brazilian free-tailed bats (*Tadarida brasiliensis*). Bats are not typical prey of Swainson's hawks, but a small population of these birds have specialized to prey upon the seasonal population of free-tailed bats outside of one cave in central New Mexico. We recorded, with stereo video, the pursuit and evasion of hawks and bats during flight, and reconstructed 3D trajectories of individuals. From the trajectories, we quantified flight behavior of predators including path, speed, attack angle, and acceleration; for the prey, we quantified escape success, escape trajectory, flight speed, acceleration, escape angle, and reaction distance. We found mixed strategies for

pursuit among hawks, and no stereotypical evasion strategies among individual bats. Our results suggest that the behavior of these populations has not likely co-evolved.

Patterns in High-altitude Bat Movement over Texas Revealed by Radar

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Movements of insectivorous bats foraging in open space and at high altitudes are very poorly understood. Advances in technology such as radar and telemetry have provided some clues. For example, Brazilian free-tailed bats (*Tadarida brasiliensis*) fly over 3 km above ground level (AGL) after leaving their cave roosts, but we do not know if they maintain those altitudes while foraging, or if they forage in proximity to other bats. Some movement patterns may depend on factors related to insects, such as their location, abundance and diversity, whereas other patterns may depend on factors related to bats themselves such as phenology of juvenile flights and density of foraging bats. These patterns vary within and among nights and seasons. We used an aerostat carrying bat detectors aloft to ground-truth a vertical radar installed in an area with many nearby colonies of *T. brasiliensis* in southern Texas, where large numbers of bats forage over agricultural fields. We then analyzed data from three seasons in 2018 and compared them to data from a nearby weather radar. We characterized bats' behaviors in several ways, including finding that bat activity peaked in most seasons at approximately 200 m above ground level though bats were active to at least 1600m from April-November. We report distributional patterns of bat activity between 50–3,000 m above ground level. Understanding these foraging movement patterns is crucial for bat conservation efforts, because flights within range of large maternal colonies occur at altitudes matching threats from growing wind energy facilities.

Observing Social Behaviors of *Eptesicus fuscus* within the Roost

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Previous research has demonstrated that big brown bats, *Eptesicus fuscus*, exhibit moderate repeatability in measures of activity and exploration, indicating consistent individual differences in behavior (i.e. personality). Such differences could serve as the basis of dominant and submissive relationships among individuals within a social group, although this idea has not been tested. The goal of this project was to conduct a preliminary assessment for the presence of dominant/submissive relationships in a captive colony of big brown bats. Specifically, we analyzed the positions of animals within their roosts (bat boxes) during three 30-minute periods within a night across a six-week period. Recordings were scored in Noldus Observer to determine the position of each animal within the group huddle (top, middle, bottom, away from group). Data were analyzed to determine if individuals differed in their distribution of positions within the group over the study period; we also examined the relationship between an individual's distribution of positions and their activity and exploration scores, which were collected as part of another study. Overall, this research provides a first glimpse into the relatively unstudied topic of the behavior of big brown bats within the roost.

Gray Bat: Recovery Progress and Future Innovation

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Following the listing of the gray bat (*Myotis grisescens*) as endangered in 1976, the U.S. Fish and Wildlife Service (Service) developed the Gray Bat Recovery Plan to guide recovery actions throughout the species' range. Extensive efforts have been undertaken to achieve recovery criteria that have resulted in significant conservation of gray bats including permanent protection of 90% of Priority 1 hibernacula. A

landmark conservation accomplishment was the protection of Coach and James Caves in Kentucky. Because of the cumulative benefits of implemented actions, populations of gray bat have increased in many areas and the overall range-wide status is considered stable. Specifically, surveys have documented marked increases in population at some of the most significant caves in Kentucky, Arkansas, Tennessee, and Missouri. Despite achievements in recovery, vulnerability to more recent and emerging threats, such as white-nose syndrome and wind energy development, could still be hampering recovery and are being assessed. Evaluation of success according to the criteria established in the Recovery Plan has proven challenging in some cases based on historic monitoring strategies. For instance, documentation of stable or increasing populations at Priority 1 maternity caves for at least 5 years (Recovery Criterion 2) has not been met due to the number of caves, access issues, and lack of appropriate survey methods. To address the discrepancy between needs and available tools, the Service and its partners are undertaking targeted efforts in research and data management that will bridge the gap and inform future recovery of the gray bat.

Partial Migration in Mexican Free-tailed Bats: Ecology and Bioenergetics of Winter Residents

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Migration is characteristic of individuals and the sum of individual migratory behaviors creates population-level patterns. When costs and benefits of migration differ across individuals some animals forego migration, resulting in partial migration systems. Within a partial migration system, we investigated characteristics and energetic strategies of non-migrants. Mexican free-tailed bats are partially migratory, with most individuals migrating south for winter while remnant populations remain at summering grounds. We hypothesized differing costs and benefits of migration between sexes would create a sex bias in winter residents, specifically predicting more males would overwinter. We hypothesized overwintering individuals would balance foraging activity and torpor use to maximize energy intake while reducing energetic costs. We predicted nighttime temperature (T_a) would correlate with bat activity, foraging intensity would be reduced through winter, and bats would enter torpor more frequently on colder nights with multi-day bouts during longer periods of low T_a. We worked at a Texas roost from September 2018–May 2019. To examine seasonal shifts in sex ratio, we captured >1000 bats and recorded their sex. To delineate shifts in foraging intensity, we collected blood from 174 foraging bats and assayed for plasma triglyceride concentration. To investigate torpor use, we measured skin temperature with temperature-sensitive radio transmitters attached to 30 bats in February 2019. There was a strong male sex bias in winter residents, resident bats regularly used torpor, and triglyceride concentrations indicated foraging on warmer nights. Winter residents balance nightly torpor and active foraging throughout winter, highlighting the extreme energetic flexibility of this sub-tropical mammal.

Effect of Hurricane Maria on Ectoparasites of Bats on Puerto Rico

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Environmental or reproductive stress potentially can lead to changes in the number and kind of ectoparasites that dwell on a mammal. Hurricane Maria, in 2017, was the most devastating storm ever to hit the Caribbean island of Puerto Rico, causing massive defoliation, destruction of woody vegetation, and disruption of natural communities. Although, cave-dwelling bats can successfully outride a serious storm by remaining in their subterranean haunts, a reduction in available food afterwards often impacts survival and reproduction. We predicted that the resulting stress, post-Maria, would result in poorer physical condition by these mammals and, ultimately, in an increase in the number of their ectoparasites. We also predicted that this effect would be more pronounced in nectarivorous/frugivorous bats and less so in insectivorous species. Fourteen months after the hurricane, we examined the assemblages living on two

nectar-feeding bats (*Monophyllus redmani* and *Erophylla sezekorni*) and two insectivorous species (*Pteronotus quadridens* and *Mormoops blainvillei*) and made comparisons to data obtained before Maria. Although many bats died after the storm and reproductive patterns were affected, the data did not support our predictions. Prevalence did not change significantly, except that we actually documented a reduction for *M. redmani*. Similarly, intensity was unchanged for three species but decreased in *M. redmani*. Diversity of parasites (Simpson's Index) decreased on *P. quadridens*, increased on *E. sezekorni*, and stayed the same for the other two bats.

Using Whole-Room Sanitation Technology to Treat Infected Hibernacula with Ultraviolet Light

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The research and management community has made significant advances in developing management strategies for white-nose syndrome (WNS). Several control agents have been shown to inhibit *Pseudogymnoascus destructans* growth; however, for most potential treatments logistical constraints challenge cost-effective treatment of entire colonies/sites and little is known about possible environmental impacts. Recently, low-dose ultraviolet (UV) radiation has joined the suite of potential treatments, but to date large-scale implementation methods have not been developed. We tested the use of whole-room UV sanitization as a feasible and ecologically safe method of reducing *P. destructans* loads from hibernaculum substrates by deploying a portable robotic console to disperse low dose UV-C light in portions of two WNS-infected mines. Prior to UV deployment, we mounted contact plates of lab-grown *P. destructans* at multiple angles along the wall and ceiling surface, and swabbed presumed bat roost areas for subsequent culture of both *P. destructans* and the resident microbial community. After UV treatment, we assessed viability of *P. destructans* among contact plates and compared presence and viability of all cultured microbes before and after treatment. We also measured sound and temperature changes in the immediate vicinity of the robotic console to consider potential impacts on hibernating bats and other cave dwelling organisms. We report on the preliminary findings of this pilot work.

The Effects of Forest Management Practices on Habitat Use by the Evening Bat

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Bats in eastern deciduous forests are declining in numbers due to habitat loss, disturbance, and disease. To promote the conservation of insectivorous bats, it is important to assess the effects of forest management practices on bat habitat use. Additionally, forest management practices may affect the sexes differently due to their unique requirements over the reproductive cycle. We therefore assessed the effects of a wide range of landscape characteristics on sex-specific foraging habitat use by the evening bat (*Nycticeius humeralis*), a forest-dwelling species, in Arkansas from June–August 2013 and 2014. We used a maximum-entropy (MaxEnt) machine-learning approach to determine the effects of 18 landscape variables (eight land-use land-cover classes, three stand types, two topography measures, normalized difference vegetation index, and four management variables) on sex-specific foraging habitat use and to further predict sex-specific areas of habitat suitability for *N. humeralis*. Our results demonstrate that female *N. humeralis* show preference for foraging near stands treated by prescribed fire, while males show preference for reforested stands. Interestingly, the area of predicted suitable habitat for male *N. humeralis* was approximately four times larger than for female *N. humeralis*, demonstrating that male *N. humeralis*

expressed more flexibility in their foraging habitat use. Because our study was conducted during the period of lactation and post-lactation, male *N. humeralis* may have been excluded from foraging in the less-cluttered burned sites by females, who were likely more energetically constrained.

The Environmental Reservoir Mediates Species Connections during Hibernation

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White-nose syndrome (WNS) has decimated bat populations across North America at an unprecedented rate. While pathogen transmission is pivotal in disease outbreaks and primarily occurs within social groups, environmental reservoirs can connect otherwise disconnected species and groups, exacerbating disease impacts. We examined transmission dynamics related to white-nose syndrome, between bat species and the environmental reservoir using a surrogate pathogen. We employed an ultraviolet-fluorescent (UVF) dust, to determine the extent of pathogen spread between species and how the environmental reservoir influences this relationship. We found that the extent of the environmental reservoir differentially influenced the connectedness between different species. Our results suggest that control measures that target the environmental reservoir have potential to reduce the impact of WNS in multiple bat species.

Development and Testing of an Anti-*Pd* Probiotic Cocktail Applied at Maternity Roosts to Reduce White-nose Syndrome-caused Mortality

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Using bacteria sourced from healthy bats in British Columbia (BC), Canada, we have derived a prophylaxis (probiotic) for prevention of white-nose syndrome (WNS). This prophylaxis contains multiple bacteria, isolated from bat wings and naturally found in some soils. These bacteria reduce the growth/germination of *Pseudogymnoascus destructans* (*Pd*). Our goal is to delay or prevent winter *Pd* growth on bats by preemptive exposure to probiotic in late summer at maternity roosts, increasing overwinter survival from WNS. This is a 'made in the west' solution because while WNS kills bats during hibernation, few locations for hibernacula are known in western North America. Instead, however, significant numbers of summer maternity locations for building-roosting bats are known and continuing to be discovered through efforts such as BC Community Bat Program, Alberta Community Bat Program, Canada's BatWatch.ca, etc. Our goal is not to treat WNS but to be proactive, reducing the ability of *Pd* to take hold on bats' wings. We present results from our successful fall 2018 'proof-of-concept' and final spring 2019 captive trails, using Yuma myotis (*Myotis yumanensis*). We will provide updates on August 2019 field implementation in Metro-Vancouver, an area likely to see *Pd* imminently given its proximity to Washington WNS detections. At these field sites we have established baseline behavioral and microbiological data, including tagging of maternity colonies of Yuma and Little Brown Myotis for long term tracking. Probiotic inoculations are passive using clay powder dusted onto roosting substrates; the applicator is cheap, easy to deploy, and easily scaled up for widespread implementation.

Are Bats Seeking Out Clean Water? A Perspective from the Namib Desert

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Water abundance, flow, and quality are key elements affecting species distributions in arid environments, yet how exactly they interact to structure specific wildlife communities is often unclear. We examined relationships between bodies of water and bat communities in the northern Namib Desert in Namibia, and explored whether these flying mammals may serve as new bioindicators of water quality. We predicted that water quality would be poorer (i.e., higher indices of electrical conductivity and ion concentrations) during the dry season and at artificial pools, and that bat species richness and activity would consequently be lower at these sites. We conducted extensive fieldwork at the terminus hot, dry season from November 2016 to January 2017 and at the conclusion of the subsequent wet season from March to May 2017, collecting water samples and acoustic recordings of bat activity at both natural springs and artificial pools. Bat species richness and overall activity increased during the wet season. Variations in water quality, however, were predicted by neither seasonality nor water body type. Although individual artificial pools harbored a greater number of bat species and activity, more than 35% of the species we detected were only recorded over natural springs. Particular species of bats rather than the entire community as a whole may still be useful water quality indicators, but other factors (e.g., roost and prey availability) require further investigation as they also likely affect distributions of Namib Desert bats.

Differences in Coding Sequence of DNA Repair Genes between Bats and Humans

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The average human life span continues to increase as does the incidence of age-related diseases. For example, cancer is currently the second leading cause of death globally. Taken together, these observations indicate a critical need for novel cancer prevention and treatment strategies. Despite the clear association between age and incidence of cancer in humans, elephants and bats are also long-lived animals, but rarely develop cancer. Elephants have been shown to be resistant to cancer due to the presence of multiple copies of the TP53 tumor suppressor gene. This protein provides elephants with a very robust response to DNA damage that may be present in malignant cells as it triggers cell death. The TP53 gene, other genes involved in DNA repair pathways, and those involved in telomere maintenance have been found to be under positive selection in bats and may explain why bats have exceptional longevity coupled with a reduced incidence of cancer; however, a direct comparison of nucleotide sequence in the coding regions among bat species and humans is lacking. We hypothesize there are nucleotide and amino acid differences among bat species and humans for genes involved in DNA damage response. We have isolated RNA from wing punch samples of *Myotis velifer* and *Tadarida brasiliensis*, converted samples to cDNA, and then obtained DNA sequence from select genes involved in these pathways. A comparison of bat DNA sequence with human DNA sequence for these genes will be discussed.

Occupancy and Activity of Bat Species in Yellowstone National Park

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Cavernicolous bats are expected to decline in the Rocky Mountain region as white-nose syndrome continues to spread, making it important to collect acoustic recordings of bat activity for continental monitoring and research. However, it is often unclear how land stewards will apply this information toward bat conservation efforts. Our goal was to compare occupancy models for 12 bat species to models of activity rates in Yellowstone National Park. To do so, we deployed SM4BAT acoustic detectors at 32 locations in

2018 and 2019, each within 5 km^2 quadrants within 10 km^2 grid-cells prioritized by the North American Bat Monitoring Program. We also drove 12 road transects within these grid-cells and compared data collected from stationary detectors to data from mobile transects using species accumulation curves. Mobile transect routes were driven twice each year, and stationary detectors remained in the field for approximately one month. We created a suite of single-species occupancy models, including detection probability and landscape-scale habitat parameters, and ranked competing models using Akaike information criterion corrected for small sample sizes (AICc). Estimates of species occupancy ranged from 4% for *Euderma maculatum* to 97% for *Myotis lucifugus*. Estimates of detection probability ranged from 30% for *Myotis californicus* and *Antrozous pallidus* to 91% for *Myotis lucifugus*. Compared to null models, occupancy models that included landscape parameters performed poorly. Conversely, models of species-specific activity rates were improved by inclusion of these variables. These data suggest that activity was more sensitive than occupancy in our study area and will likely reveal population disturbances before changes in occupancy estimates will.

Detection of Tarnished Plantbugs, Apple Maggots, and Codling Moths in Bats' Diet in Michigan Apple Orchards

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Michigan is ranked third for apple production in the USA. Insectivorous bats provide a key ecosystem service for some agriculture systems and may provide one for southern Michigan apple orchards by consuming apple pest insects. My thesis evaluates if big brown bats (*Eptesicus fuscus),* silver-haired bats *(Lasionycteris noctivagans),* eastern red bats *(Lasiurus borealis),* and hoary bats *(Lasiurus cinereus)* consume three economically-important apple pests: tarnished plantbug (*Lygus lineolaris*), apple maggot (*Rhagoletis pomonella*), and codling moth (*Cydia pomonella*). The objective provides farmers with sustainable and inexpensive alternatives to pesticides. I will capture bats and collect fecal samples from 4 organic and 4 conventional orchards in southern Michigan. Target insects will be collected from pheromone traps during surveys to measure relative abundance. Molecular data may not be available, but I will be extracting DNA from the fecal samples and amplifying the DNA using polymerase chain reaction (PCR). DNA will be analyzed for target insect presence or absence using the genetic technique restriction fragment length polymorphism (RFLP). Positive samples will be categorized by bat species and orchard type followed by comparing them to the total number of samples, across bat species, and between conventional and organic orchards as well as to samples collected each night. Results analyzed by the conference will include relative bat and insect abundance. I predict my results will show bats are eating these pest insects, especially during peak emergences. My predictive conclusion is bats can provide farmers with an alternative pest control method they can implement within their current practices.

Summer and Autumn Roosting Ecology of *Myotis septentrionalis* in Pennsylvania

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Knowledge of the roosting ecology and behavior of several bat species is largely based on summer studies. Although less studied, autumn is an important time for temperate bats to migrate and prepare for hibernation. Furthermore, some species traditionally considered "cave bats" are recently discovered to also hibernate outside of caves, possibly in structures similar to their autumn roosts, demonstrating the need to better understand autumn habits. Our goal was to study summer and autumn day-roosts of *Myotis septentrionalis* and to determine the timing of autumn migration. To do so, we tagged male and female northern myotis belonging to a remnant population in central Pennsylvania with traditional radio-transmitters and coded NanoTags. We tracked tagged bats to their roosts each day and collected a suite of habitat measurements at each tree. We also constructed seven automated telemetry stations within the study

area to help determine when bats migrate. We used multinomial regression and an information theoretic approach to compare biologically informed models predicting differences between male, female, and available (unused) trees during summer and autumn. At the time of abstract submission, we radio-tracked 22 bats to 66 day-roosts. During summer, females were most likely to use snags of larger diameter located in stands with higher basal areas of live and dead trees than males. Males also selected smaller trees than those available. Autumn data will be presented. These data illustrate the importance of snag availability for remnant bat populations and will provide an important baseline for comparisons with autumn roosts.

The Luxury Effect Beyond Cities: Bats Respond to Socioeconomic Variation across Landscapes

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The luxury effect describes the positive relationship between affluence and organismal diversity or activity in urban ecosystems. Previously, the luxury effect has been found in two bat species within a city, the red (*Lasiurus borealis*) and the evening (*Nycticeius humeralis*) bat. We were interested in determining if the luxury effect scaled beyond a single city and across multiple bat species. We examined landscape scale bat activity patterns from seven bat species to test for the luxury effect, and bat activity and land cover associations. We used mobile transect data from the North American Bat Monitoring Program in North Carolina from 43 sites collected from 2015 to 2018. Land cover data were from the 2016 National Land Cover Database and income data from the 2016 American Community Survey 5-year estimates. We constructed generalized linear mixed models to identify bat-land cover and bat-income relationships. Across landscapes, activity of red bats and evening bats was positively correlated to income independent of land cover, a result consistent with the previous single-city study. We found a negative relationship between hoary bat (*Lasiurus cinereus*) activity and income. All species had specific land cover associations. We conclude that the luxury effect is an ecological pattern that can be found at a broad spatial scale across different landscapes. We suggest the need for multi-scale ecology studies to identify the mechanism(s) underlying the luxury effect and that the luxury effect could cause inequity in ecosystem services.

Species and Genetic Diversity of Bats in the Southern Dutch Caribbean: Aruba, Bonaire, and Curaçao

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The Caribbean islands of Aruba, Bonaire, and Curaçao off the north coast of South America have not been comprehensively reviewed for species diversity and genetic variation of bats or compared to taxa across the Neotropics. The objectives of our study are to see if there are distributional and phylogeographic patterns with the continental mainland and insular species in the New World tropics. Mist nets and harp traps were used to survey bats on these 3 islands over a 1-month sampling period. The mitochondrial gene cytochrome c oxidase subunit 1 was sequenced to analyze DNA diversity, which was summarized by phylogenetic trees. Of the 11 species previously documented from the southern Dutch Caribbean, we recorded 8 species of bats, including a taxonomic change (*Artibeus lituratus* instead of *Artibeus jamaicensis* on Curaçao), range extension (*Myotis nesopolus* on Aruba), and update of local island extirpation (*Molossus molossus* have been found again on Curaçao). All species found in the 3 islands are most closely related to populations in South America with 5 phylogeographic patterns exhibited, including (1) 5 species only associated with South America; (2) 3 species more widely associated with Central America; (3) 1 species further associated with the Lesser Antilles; (4) 1 species associated with the Lesser Antilles; and (5) 1 species further associated with the Greater Antilles. In conclusion, there are no endemic species in the

southern Dutch Caribbean and taxa have a closer affinity to South America than to the Greater or Lesser Antilles.

Responses of Temperate Bats to Silvicultural Treatments—A Qualitative Synthesis

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Most bat species depend on forests for roosting, foraging, and drinking during part or all of their life cycles. Many of the world's forests are managed using a variety of silvicultural treatments and over the past 40 years, researchers have studied the responses of bats to these treatments. I conducted a qualitative synthesis of the literature on stand level responses of temperate insectivorous bats to silvicultural treatments to determine what treatments may be most compatible with conservation of temperate insectivorous bats and to guide future research. Eighty-eight studies from Canada, the United States, Europe, Australia, and New Zealand met review criteria. Based on the proportion of negative responses to treatments, bat foraging and commuting habitat use was less affected by silvicultural treatments than roost habitat use. Mid-rotation treatments such as thinning and prescribed fire, which reduce clutter while retaining overstory structure, appeared to have fewer negative effects and more neutral and positive effects than treatments that remove all or part of the overstory and eventually result in thick second growth forests. Based on caveats identified in the studies included in this synthesis, I suggest that future studies: 1) strive to account for treatment effects on detection probability of bats when using acoustic detectors, 2) examine responses of bats to silvicultural treatments outside the maternity season, 3) examine demographic and physiological responses to silvicultural treatments in addition to changes in habitat use, and 4) use stand level data to model forest management effects across the landscape.

Effects of Omnidirectional Microphone Placement and Survey Period on Bat Echolocation Call Quality and Detection Probabilities

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Many factors, including microphone type, affect the quality of acoustic calls recorded by bat detectors and detection probabilities of individual species. Because omnidirectional microphones tend to have a shorter range and record more noise than directional microphones, it has been suggested that these microphones be set farther from reflecting surfaces. Our objective was to determine the effects of microphone height (1.5 m, 5 m, and 9 m), distance from forest edge (1 m, 3 m, and 5 m), and survey timing on the number of bat files recorded, quality of recorded files, the proportion of identifiable files, and the probability of detecting individual species. We deployed 3x3 arrays of two types of bat detectors with omnidirectional microphones at two sites in Kentucky during two survey periods. We found little evidence for effects of microphone height or distance from forest edge on call quality or detection probabilities of any species. In contrast, survey period significantly affected the number of files, the proportion of high-quality files, the proportion of identifiable files, and the probability of detecting individual species and the length of the recording session significantly affected the probability of detecting some species. Thus, it appears that biologists have some latitude when placing detectors with omnidirectional microphones on the landscape but timing of surveys should be considered when designing and analyzing bat acoustic survey and monitoring studies.

Effects of Forest Fire on the Bat Community in Waterton Lakes National Park

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The Kenow Wildfire occurred in Waterton Lakes National Park (WLNP) in southwestern Alberta, Canada in September 2017. The wildfire, started by lightning, burned 38% of WLNP and resulted in a

predominantly 'very high' burn severity throughout the park. As the wildfire occurred at the end of summer after bats had dispersed to their wintering grounds, there was likely no direct mortality. Therefore, any changes to bat diversity and relative abundance can be attributed to the wildfire's impact on the environment. Past studies have suggested that bats respond positively to fires, by increasing the roosting and foraging opportunities for most species. From 2015–2017 bat acoustic surveys were conducted by Parks Canada staff in WLNP from late June to early August. Acoustic monitoring was continued after the Kenow Wildfire (2018–2019), providing the opportunity to compare bat diversity from before the fire to levels after the natural disturbance. During the summer of 2019 (June–August), bats were also captured using mist nets, and body and reproductive conditions were assessed. Capture data from 2019 was compared to data from trapping surveys in 2011 and 2012. Little brown Myotis reproductive females were also radio-tagged and tracked to their maternity roosts in 2019. Preliminary results of capture data show a strong preference for anthropogenic roosting structures and decreased species diversity compared to 2011 and 2012. The analysis of acoustic results is in progress, however, given the lower than expected species diversity, I predict this to also be reflected in the acoustic results.

Effects of Open Aerospace Habitat on Aerial Insectivorous Bat Communities in Lamanai, Belize

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Neo-tropical bats stratify vertical aerospace due to adaptations associated with diet, foraging strategy, echolocation and size. Aerial insectivores, in particular, forage in open, non-cluttered spaces high in the aerosphere. Due to their use of open aerospace, these bats are not expected to decline with habitat disturbance and deforestation. However, sensitivities to habitat changes may vary from species to species. Passive acoustic monitoring was used to assess community structure of aerial insectivorous bats from three open aerospace habitats in Lamanai, Belize. Recordings were taken over a lagoon (natural habitat), over an unused airstrip (cleared forest) and above a lodge with a flood light (disturbed forest with anthropogenic light). Nine total nights of recordings were analysed with 20,195 bat calls identified. Richness was found to be unaffected by habitat type, however, community composition differed on both a family and genus level across all three sites. Activity decreased over cleared forest but increased with disturbance and anthropogenic light. Bats in Mormoopidae family were more sensitive to habitat disturbance, while Vespertilionidae became the dominant family in sites with anthropogenic light. Understanding the changes to community structure in neo-tropical aerial insectivorous bats allows us to better include them in conservation projects and studies in the future.

Functions of In-flight Social Calls of *Eptesicus fuscus* and *Nycticeius humeralis*

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Bats produce social calls while in flight, and the behavioral context of in-flight social calling in bats is not well understood. We have identified in-flight social call types produced by the big brown (*Eptesicus fuscus*) bat and the evening (*Nycticeius humeralis*) bat. Social calls produced by these species contain species-specific signatures and are produced during different behavioral contexts. *Eptesicus fuscus* complex social calls frequently appear with foraging buzzes suggesting a competition function, Upsweeps and downsweeps of *E. fuscus* and *N. humeralis* occur most often when there are multiple species of bats present suggesting a group cohesion function. In this study we conducted playbacks in Greensboro, North Carolina, USA to identify the functions of common social calls produced by these species. We compared changes in bat activity between social call playbacks, echolocation call playbacks, and silent control trials. We predicted that *E. fuscus* complex social calls would have a negative effect on total bat echolocation

calls, whereas upsweeps and downsweeps would increase total bat echolocation calls. We found no effect of complex or downsweep playback calls on subsequent bat activity, however, we found that playback of *E. fuscus* upsweep social calls decreased total echolocation calls. Therefore, our results suggest the call does not facilitate group cohesion. Our study is ongoing with additional social call types that will be presented. There are rich social behaviors that can be studied from the response of free flying bats to social calls through controlled playback experiments.

Does Metabolic Rate Predict Activity and Cooperative Behavior in Common Vampire Bats?

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Individual variation in sociality could be linked to metabolism and energy expenditure due to energetic costs and benefits associated with cooperative investments. Individual differences in social behaviors, like allogrooming, might be driven merely by individual differences in activity level, a trait associated with high metabolic rates. I hypothesize that social or cooperative individuals are more active than those individuals who do not engage in social interactions as often. Resting metabolic rate (RMR) of 22 bats was estimated from oxygen consumption data, measured using open-flow respirometry, and correlated with an individual's average activity level and amount of social behavior. Activity level, quantified by the amount of movement within an enclosed arena, and social behavior were evaluated using video footage of each bat while isolated and while housed with conspecifics, respectively, after a fasting period to encourage food sharing. Preliminary data on RMR among the bats show high intra-individual variation. Metabolic rates of these individual bats will be linked to further research on individual differences in vampire bat sociality and in the underlying neuroendocrine mechanisms. Variation in metabolic rates could largely determine which individuals are most central in a social network.

Dietary Patterns of Big Brown Bats in a Diverse Landscape

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Over the past decade, advances in high-throughput sequencing of DNA extracted from bat guano have allowed researchers to gain new insight into the foraging ecology of bats. Recent work has provided new perspectives on basic biological questions, including inter-/intraspecific competition and seasonal differences in prey selection, as well as applied topics such as the potential importance of bat predation for insect pest management. Here we expand on this emerging knowledge base with an analysis of big brown bat (*Eptesicus fuscus*) guano collected from six maternity colonies across a diverse New Jersey, USA landscape over a 26-week period in 2017. Using metabarcoding of 419 samples (~10 guano pellets per sample), we identified 2,815 amplicon sequence variants (ASVs), corresponding with 552 species from 151 arthropod families. The most common taxa included Lepidoptera (moths), Coleoptera (beetles), and Diptera (flies), as well as the primarily aquatic Megaloptera, Ephemeroptera, and Trichoptera. Prey included many agricultural (e.g. brown marmorated stink bug, tarnished plant bug) and human (e.g. mosquitos) pests. Prey diversity differed seasonally and among colonies, largely driven by landscape-level characteristics and time of year.

Befriending Bats: Using Citizen Science for Acoustic Data Collection in an Urban Park

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Involving citizens in the collection of scientific data is an effective method of engaging people to learn more about local wildlife, while also adding to the database of scientific studies. Projects such as Neighbourhood Bat Watch have allowed for citizens to submit bat sightings online, while few others have implemented on-the-ground data collection. The Native Bat Conservation Program at the Toronto Zoo partnered with Friends of Cedarbrook Park to conduct walking transects and collect acoustic monitoring data on bat species in a suburban park in Toronto, Ontario, Canada. Volunteers were initially taken on one evening bat walk through Cedarbrook Park to learn about the species of bats found in Ontario, while also being trained to use a PeerSonic acoustic recorder and record bat observations on a datasheet. Volunteers are completing this 4 km walking transect on a biweekly basis throughout the summer, which will result in a total of nine nights of data collection. *Eptesicus fuscus* is the most commonly observed species in the area, followed by *Lasionycteris noctivagans* and *Lasiurus cinereus*. On each night of data collection, members of the community were invited to join the walk, now lead solely by volunteers. Devoted volunteers also began undertaking data analysis on their own based on visual observations during each night. The success of this project was dependent on the commitment of the Friends of Cedarbrook Park volunteers to continue collecting data on a regular basis, allowing for more information of bat activity in the city.

Modeling and Mapping Western Bat Hibernaculum Suitability Before and After *Pd* Exposure

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As the fungal pathogen *Pseudogymnoascus destructans* (*Pd*) and resultant white-nose syndrome (WNS) continues to advance into western North America, it will infect new bat populations, species, and hibernacula. Western North America's extensive public lands host the continent's highest bat diversity, so it is critical that western land managers have the information they need to anticipate and address the conservation needs of WNS-susceptible species. We estimate suitability of potential winter hibernaculum sites continuously across five bat species' ranges in the West, then predict future changes in suitability with *Pd* exposure by integrating spatially explicit pre- and post-exposure estimates of winter survival capacity with high-resolution landscape data. We estimate winter survival capacity from a mechanistic survivorship model based on host bioenergetics, *Pd* characteristics, and climate conditions. Leveraging the Google Earth Engine platform for spatial data processing, we use boosted regression trees to relate these estimates, along with key landscape attributes, to bat occurrence data in a hybrid correlative-mechanistic approach. Winter survival capacity, topography, land cover, and access to caves and mines are important predictors of winter hibernaculum selection, but their relative importance varies among species. *Pd* exposure is generally expected to decrease winter survival capacity and in turn reduce hibernaculum suitability, often in areas currently estimated to be most suitable. We aim to help managers anticipate which species are most susceptible to declines, and where, to implement effective conservation strategies for western bats. We conclude by discussing the implications of interacting impacts of *Pd* and climate change on hibernaculum selection and survival.

Insect Perspective on High Altitude Bats

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Many bats are known to fly at high altitudes. Not all high-flying bats feed aloft, but over a dozen species belonging to four bat families are now documented to do so. These bats share features of morphology, flight dynamics, echolocation, and feeding strategies that are common to open-airspace foragers, but they may also face challenges unique to high altitude environments. While the ecology of high-altitude flight has received little attention from bat ecologists, insects aloft have received extensive study. Here we posit that studies of nocturnal, high-flying insects can inform us on the challenges faced by bats at high altitudes, and on opportunities presented to the bats. Layered structure, waves, and circulatory motions are dominant features of the night sky. Temperature, wind speed, relative humidity, and air pressure vary at different altitudes but not necessarily as smooth gradients. Temperature and humidity may increase with altitude, and bats and insects at altitudes of several 100 m above the ground may be flying in air temperatures as much as 10° C above surface temperatures. Insects form layers at altitudes with higher temperatures and favorable winds, and insects actively seek these habitats, which may result in patches of resources that influence the social and foraging behavior of bats. In mountainous and hilly terrain, the rapid ascents at night of insects are assisted by thermally assisted winds that are deflected upslope. Bats may use the same winds for their own purpose.

The Influence of Microclimate Manipulation on Hibernation Physiology and White-nose Syndrome

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Microclimate conditions affect hibernation physiology and the dynamics of white-nose syndrome (WNS). Other studies have investigated the effect of temperature, few have considered humidity, and no study has considered the combined effects of both. To test the influence of temperature and humidity on hibernation and WNS, we conducted a captive inoculation study with bats housed across a range of temperature (5–11°C) and potential evaporative water loss (pEWL; 0.5–1.6 hPa). We collected 70 *Perimyotis subflavus* from Mississippi, inoculated them with *Pseudogymnoascus destructans,* and maintained them in environmental chambers for ~3 months. We used quantitative magnetic resonance to measure body composition, and quantified fungal load (qPCR), UV fluorescence (wing photos), and histology. Our design allowed examination of independent effects of temperature and humidity. We found higher temperatures and pEWL increased arousal frequency, but temperature also independently increased energy expenditure through other mechanisms. We did not observe behavioral symptoms of WNS. Wing photos revealed little UV fluorescence, fungal loads remained low, and few bats were observed with diagnostic histopathology characters of WNS after 82–86 days of hibernation, longer than the predicted duration of Mississippi winter. Lack of WNS severity is consistent with previous captive studies that suggest symptoms of WNS increase rapidly late in hibernation (>90 days). Our experimental results suggest dynamics and outcomes of WNS may be different in regions where winters are shorter. This finding emphasizes the importance of continued research and monitoring in these regions to understand the implications of WNS across a growing geographic range.

Modeling Bat Species Co-occurrence in Dubuque County, Iowa

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Insectivorous bats are important mammals for agricultural pest control. Native bats are threatened by habitat loss and fragmentation, disease, wind turbines, and climate change. Nine species of bat are known for eastern Iowa including the Federally Endangered *Myotis sodalis* and Federally Threatened *M. septentrionalis*. We sought to evaluate bat co-occurrence in eastern Iowa as they adapt to increasing threats and are potentially restricted into smaller desirable habitats. Co-occurrence data can give insight into interspecific interactions and inform management and conservation strategies for Iowa's bats. Acoustic data were obtained from 22 sites within Dubuque County (Iowa) during summer 2018. From these data, 18,399 calls were identified through Kaleidoscope with all nine native bat species detected. To assess co-occurrence, we ran ten single-season two-species Occupancy models in Program Presence for five species (*Eptesicus fuscus*, *Lasiurus borealis*, *M. lucifugus*, *M. sodalis*, and *Perimyotis subflavus*). Four species (*Lasionycteris noctivagans*, *Lasiurus cinereus*, *M. septentrionalis*, and *Nycticeius humeralis*) were detected too rarely or frequently for reliable modeling. A *Phi* value equal to 1 suggests that the two species occupancy patterns are independent, a value greater than 1 suggests stronger co-occurrence that is not independent, and a value less than 1 suggests avoidance. While most models yielded *Phi* values very close to 1, a few suggested potential co-occurrence or avoidance between species pairs. Notably, a strong co-occurrence of *M. lucifugus* and *M. sodalis* (*Phi* = 1.57) may reflect challenges in distinguishing between the two species' vocalizations and not reflect the presence of *M. sodalis* in the area.

The Advancing Front of White-nose Syndrome: Using Bat Dispersal Models to Explain Disease Spread

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The emergence of a new pathogen can cause disastrous declines in otherwise healthy species, a fact illustrated all too clearly by white-nose syndrome. Relating physical landscape structures to pathogen incidence has the potential to estimate the risk of disease spread on a broad geographical scale and identify specific paths in a landscape that a pathogen can take. White-nose syndrome presents a clear test case for the use of predictive disease spread models. This work combines metapopulation modeling with SIS disease spread modeling to provide insight into ways that landscape structure and the spatial position of hibernating colonies impedes or promotes the spread of white-nose syndrome. Multiple models of bat dispersal between hibernacula among *Myotis lucifugus*, *Eptesicus fuscus*, and *Myotis sodalis* in the eastern United States are constructed and an overlaying SIS model applied. Differing models adjust the effect of spatial distance, topographic features, and cross-species interactions. The generated disease trajectories between known hibernacula are compared to the observed spread of white-nose syndrome. The greatest similarity to the historical spread of white-nose syndrome is found in dispersal models modulating exchange of bats between hibernacula by intervening topographical slope and allowing limited cross-species interaction. Results from these models can allow for predictive trajectories of white-nose syndrome in as of yet unaffected areas. This project seeks to identify features of populations and regions that are at greater risk of spreading white-nose syndrome and to inform decision-making by managers.

Comparative Analysis of DNA Damage Response Gene Regulation in Bats and Humans

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Genome maintenance and prevention of DNA damage contribute to increased longevity and cancer resistance. Bats are exceptionally long-lived and cancer resistant, relative to humans. Furthermore, bats

have been shown to have genome-level differences in several genes involved in the DNA damage response (DDR) and tumor suppression compared to humans. However, the physiological consequence of these differences in bats is not currently known. In order to test the hypothesis that the observed genome-level differences in bats contribute to enhanced DDR, we will identify and analyze gene regulatory sequences of genes with established roles in DDR. We have evidence to suggest that several of our candidate genes are coordinately de-regulated in the context of cancer in humans. This supports the hypothesis that these genes are regulated by the same, or similar, upstream factors in humans. Transcriptional start sites (TSS) for our genes of interest will be determined, and candidate gene regulatory regions will be generated by PCR amplification of 1500–2000 bp upstream of the TSS. Candidate promoter sequences will be tested for their ability to drive gene expression in two bat cells lines. Those sequences capable of driving gene expression will be considered promoters, and analyzed further. Transcription factor binding site analyses will be performed on sequenced regulatory regions using promoter analysis software, and the promoters derived from bats will be compared to their human counterparts using DNA analysis software. We predict that differential expression between bats and humans arises from sequence differences in the promoter region of each gene.

Development of Auditory Sensitivity in the Big Brown Bat

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Bats have excellent hearing, which they use for orientation, alerting functions, communication and prey detection. We studied development of auditory sensitivity in the big brown bat (*Eptesicus fuscus*). The opening of the outer ear canal in both ears occurred until postnatal day (PND) 7 in 23 of 30 pups; the earliest time when both ears were open was PND 4, and the last time was PND 11. We then documented progressive development of hearing sensitivity using auditory brainstem response (ABR) recordings. The ABR is a synchronous neural response evoked by acoustic stimulation and represents the summed activity of neurons in the auditory pathway between the cochlea and upper brainstem. Recording ABRs is a relatively non-invasive procedure, with measurements conducted in awake or lightly anaesthetized animals and repeated in the same individual to track hearing onset and development. We measured hearing thresholds in 22 *E. fuscus* every three days between PND 10 and PND 31. Nursing pups were returned to their mothers between recordings. Further measurements were taken in some bats at PND 60, PND 90, and after one year. There was a dramatic shift in auditory thresholds across development for frequencies between 4 and 100 kHz. Prior to PND 13-16 when pups were still non-volant, most bats were unable to hear frequencies above 48 kHz; however, sensitivity to higher ultrasonic frequencies increased with age. Notably, this change occurred near the time when young bats start learning to fly and echolocate.

Home Range and Habitat of Northern Long-eared and Tri-colored Bats during Fall Swarm

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Fall swarm is an essential period in the annual life-cycle of bats. Foraging during this period is under-studied in comparison to the summer maternity season. We completed a study to describe landscape-use during fall swarm and create a resource for managers tasked with decisions about the future viability of northern long-eared (*Myotis septentrionalis*) and tri-colored (*Perimyotis subflavus*) bats on their conservation or management lands. In 2018, we conducted a ground-based foraging study during autumn on these two species in the Boston Mountain ecoregion of northeastern Oklahoma. Four northern long-eared and 13 tri-colored bats were radio tagged and synchronized azimuths were gathered from five stations for five nights. Mean home range of northern long-eared bats was 196.0 ± 83.7 ha, and mean location distance (n=84) from the swarm site was 1,337.8 ± 192.3 m. Mean home range for the tri-colored bat was

91.6 ± 11.8 ha, and mean location distance (n=103) from the swarm site was 609.0 ± 76.6 m. Field surveys provided finer-scale habitat data than available from the National Land Cover Dataset'; compositional analysis and linear regression showed that both species use breaks in the forested landscape, such as trails, to a greater degree than those habitats are available on the landscape. Both species used second-order and larger streams more than first-order streams, wetlands, ponds, or lakes.

Spring and Summer Energetics of *Myotis lucifugus* Recovering from White-nose Syndrome

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White-nose syndrome (WNS) causes hibernating bats to arouse too often in winter and use fat reserves too quickly. Therefore, bats that survive likely emerge in spring in poor body condition making it difficult for females to support reproduction. Despite the importance of reproduction, little is known about active season energy balance and reproduction of WNS survivors. We studied thermoregulatory energetics of reproductive female little brown bats (*Myotis lucifugus*) at the WNS invasion front in central Canada to test two hypotheses: 1) Carry over effects of the disease are influencing the torpor behaviors of the surviving females in the spring; and 2) Torpor expression by individuals is negatively correlated with severity of WNS-associated wing scarring. We captured bats from a maternity colony in northwestern Ontario and assessed wing damage using the Reichard index. We attached temperature-sensitive radio transmitters during pregnancy (June 2017, n=13) and lactation (July 2017, n=13). We then used a datalogging receiver to record 122 bat-days of skin temperature data. Consistent with our hypothesis WNS surviving females are changing their torpor patterns, however not until later in the active season. This pattern only occurs in bats who had evidence of WNS damage. Torpor saves energy but delays offspring growth so our study will shed light on implications of WNS for reproduction by survivors. This is critical for understanding the potential of survival traits to evolve in endangered bat populations and aid population recover.

A Formal Technique for Monitoring Abundance of Bats on Talus Slopes

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Recent emerging threats to bat populations highlight a need for improved monitoring datasets. About 40% of bat species in North America are associated with rock-formations in at least part of their range, and status of many of these is poorly understood. We tested the efficacy monitoring one such species, the eastern small-footed bat, using visual surveys on talus slopes in Virginia. Bats were surveyed in random plots of varying size by teams of 2 to 3 observers. We assessed performance of the method at 6 sites, by comparing effects of observer, site, plot identity, season (pregnancy or lactation) and year on the number of bats counted per plot, with zero-inflated mixed-effects models. We also examined differences in outcomes for expert versus novice observers, and used trials with radio-tagged bats to quantify how often (and why) observers missed bats. Bat abundance varied significantly among plots and sites, but was similar among observers, years and between seasons. Novices tended to search more crevices and found slightly fewer bats than experts. Observers missed 36% of (4 of 11) bats; half were because bats were impossible to see, and half were visible but simply overlooked. Overall, visual surveys were surprisingly effective for quantifying eastern small-footed bats on talus slopes. Using multiple observers likely mitigated against observer bias. Visual surveys should be considered for use with other species of talus-roosting bats, especially in regions such as western North America where other forms of data are often lacking.

Using Prepared Nectarivorous Bat Specimens for Pollination Studies: An Example with Bat-pollinated *Burmeistera* (Campanulaceae) from Ecuador

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Specimens from biological collections are invaluable for bat ecology and evolution studies. In nature, nectarivorous bats often carry copious pollen from multiple plant species on their fur, making bat-pollinated flowers prone to receive heterogeneous pollen loads. We used prepared nectarivorous bat specimens (*Anoura geoffroyi*) to evaluate how heterospecific pollen deposition (HPD) affects reproduction of two sympatric species of bat-pollinated *Burmeistera* (Campanulaceae) from Ecuador. We created pollen mixtures that differed in the ratio of heterospecific:conspecific flowers used to make them (1:3; 2:2, and 3:1), applied them to flowers using the bat specimens, and quantified abortion rates, seed number, and seed mass of the resulting fruits. For *B. borjensis*, greater amounts of HPD decreased seed production and seed mass whereas no significant effect was detected in *B. ceratocarpa*. *Burmeistera borjensis* aborted more fruits than *B. ceratocarpa* (44.1% vs. 18.8%), however, fruit abortion rates were not affected by HPD in either species. We found differential effects of HPD on the reproduction of our study species: increasing HPD reduced seed production and seed mass of *B. borjensis* but not in *B. ceratocarpa*. Because prior work showed that interspecific pollen transfer by bats in nature is much higher from *B. borjensis* to *B. ceratocarpa* than in the opposite direction, we suggest that tolerance to HPD helps *B. ceratocarpa* to successfully coexist with its congener while sharing their bat pollinators. Our study demonstrates a novel use of nectarivorous bat specimens for pollination studies and suggests that tolerance to HPD might be common among bat-pollinated plants.

Evolution of the Major Histocompatibility Complex Class-I in New World Bats

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Host-Pathogen interactions have led to an endless evolutionary race, in which pathogens exert a strong selective pressure over the host, which consequently has developed mechanisms of defense known as the immune response. This response is divided in two types: a fast and non-specific innate response and a slower but highly specific adaptive response. One of the most important molecules of the adaptive response is the Major Histocompatibility Complex (MHC), a multigenic family that recognizes and binds the pathogen peptide and present it to T cells that triggers the immune response. MHC genes are under strong balancing selection and are considered as the most polymorphic loci in vertebrates. The order Chiroptera is one of the most interesting groups to study immune evolution, due to it has been suggested that bats possess a unique and extremely polymorphic immune system due to its role as natural reservoirs of viruses. By performing whole RNA sequencing and *de novo assembly* of liver transcripts in five species of microbats, each one classified into a different family, we made a qualitative analysis of the MHC class I transcripts, responsible for the recognition of virus. We assembled the complete peptide binding region encoded by exon 2 and 3, both exons were under positive selection. A unique insertion of 5 amino acids was detected in some exon 2 sequences among the five species. This insertion may allow the recognition of longer peptides, that along with the maintenance of ancestral MHC-I loci might favor the effectiveness of defense against viruses.

Recovery of Little Brown Myotis (*Myotis lucifugus*) Surviving and Thriving after White-nose Syndrome

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Since 2006, white-nose syndrome (WNS) has caused precipitous declines of some bats in North America. But the effects are not consistent over the area from which WNS has been reported. WNS was first reported in southern Ontario in 2010 and significant mortality observed in 2012. For five years from 2014 to 2018 we monitored a population of *Myotis lucifugus* at a roost in southern Ontario. We observed stable growth, returns of adults and recruitment of subadults into the adult breeding population. We radio-tracked bats to nine other roosts within a 2-km radius and documented variable use of roost types. We characterized fidelity to roosts and movement patterns among roosts. We used passive implanted transmitter tags to quantify the association of individuals to the roost at various life stages through the year. In spring, some bats showed infection by WNS, but these symptoms disappeared later in the summer. This population appears to be doing well and could be a source for recovery. Three other species of bats use the roost as well. The roost functions in several manners including as a migratory stopover area, a maternal roost, a nocturnal resting area between foraging bouts, and possibly as a male swarming area. Three species of *Myotis* used the roost, all in different manners. M*yotis lucifugus* routinely moved among roosts and it appeared as though the presence of a network of roosts was important to this population.

Kinematic Comparison of the Recovery Maneuvers between Two Bat Species

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Bats show outstanding agility and control of their flight. Even so, collisions are commonplace, as they often fly in close proximity to one another and must navigate their surroundings through turbulent conditions. They minimize the impact of these collisions through compliant elements in their wing structure and dynamic actuation of many degrees of freedom to quickly recover stable flight. Here, we compare the recovery response of both *Rousettus aegyptiacus* and *Carollia perspicillata.* Previous studies indicate that wing mass moments of inertia scale linearly with body mass. Consequently, we hypothesized that both of our study species would employ similar passive dynamics to respond to and recover from perturbation. To test this, we trained five *R. aegyptiacus* and four *C. perspicillata* to fly through a small window bisecting a corridor (1.5 x 6.0 x 2.0m). On test trials, an air jet scaled to 2.5x each bat's body weight struck one wing after bats passed the window. We analyzed the 3D kinematics using multi-camera recording of 15 landmarks on each bat, and compared responses between species. We found that the perturbation induces less body rotation in *R. aegyptiacus*. These results reject our hypothesis, and indicate that factors other than wing moment of inertia play a role in stabilizing flight. In natural conditions, *R. aegyptiacus* typically fly greater distances in more turbulent conditions than *C. perspicillata*, which may have exerted selective evolutionary forces for highly effective reactions to environmental perturbations. Further research can help reveal the underlying stabilizing mechanisms used by *R. aegyptiacus.*

The Long Stems Characteristic of Bat-pollinated Flowers Greatly Reduce Bat Search Times while Foraging

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Botanists have long noted that flowers adapted to bat pollination tend to be particularly well-exposed, with long stems that position them away from other foliage. The selective advantage of this trait, however, has remained obscure. We captured nectar-feeding bats (*Anoura geoffroyi*) in cloud forests of the

Colombian Andes and held them in flight cages to test the effects of floral exposure on foraging behavior. Ten bats were held for 3 days each, and in a series of trials we timed how long it took to locate a flower (of *Burmeistera succulenta*) affixed to one of six poles placed in the cage. Bats were exposed to four treatments: long or short floral stems, in either simple or complex backgrounds. Complex backgrounds included arrays of leaves around each pole, while simple had none. Flowers were randomly shifted after each trial so that bats did not simply learn location. In simple backgrounds, bats showed no difference in search times for long vs. short stems, while in complex backgrounds, bats took nearly twice as long to locate short-stemmed flowers. This suggests that increased flower exposure allows bat echolocation to better distinguish floral echoes from background clutter echoes. This, in turn, would favor the evolution of long stems to ensure that flowers are discovered by bats and thus can successfully reproduce.

Behavioral Responses of Hibernating *Eptesicus fuscus* to Variable Humidity

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During winter, when food is limited and ambient temperature is cold, many mammals hibernate, reducing body temperature and metabolic rate via bouts of torpor. Hibernators spend most of their energy during hibernation on costly arousals from torpor and white-nose syndrome (WNS) exacerbates energetic demand by increasing arousal frequency. Bat species vary in WNS susceptibility and *Eptesicus fuscus* appears resistant, although underlying resistance mechanisms are unknown. Evaporative water loss (EWL) and dehydration can increase arousals in hibernators and WNS also increases EWL, which suggests mechanisms affecting water balance could be involved in WNS resistance. We tested the hypothesis that *E. fuscus* relies on behavioral flexibility to maintain water balance in conditions of varying humidity. We predicted that hibernating bats in a dry environment would drink more frequently during arousals, and exhibit more huddling behavior during torpor, compared to bats in a humid environment. We housed groups of individually marked hibernating *E. fuscus* in one of two temperature- and humidity-controlled incubators set at 8°C and either 98% or ~50% relative humidity (110 days; n=10 per treatment). Infrared cameras continuously monitored bats from above to quantify arousals and huddle size, and from the side to quantify drinking behavior. As predicted, bats in the dry incubator showed higher drinking frequency during arousals, and remained in a single, more compact huddle during torpor. Our results suggest that behavioral flexibility plays a role in reduced WNS susceptibility for *E. fuscus* and have implications for understanding WNS susceptibility in other bat species.

The Influence of Sensory and Biomechanical Modules on the Evolution of Neotropical Leaf-nosed Bats

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Sensory and mechanical structures share space in the head but have different spatial, geometric and mechanical requirements. We evaluated the co-evolution of mechanical and sensory structures and their association with the explosive radiation of Neotropical Leaf-nosed bats. We sampled all families within the noctilionoid tree (Phyllostomidae, Noctilionidae, Mormoopidae, Furipteridae, and Thyropteridae) and the major dietary niches within Phyllostomidae, for a total sample size of 42 individuals from 35 species. External landmarks were used to capture the shape of five areas of the cranium that reflect structural

robusticity and contribute to bite-force performance (the cranial base, external vault, palate, face, and the zygomatic- glenoid region). Internal landmarks were placed on structures that house sensory systems (the olfactory bulb, petrous part of the temporal bone, internal vault, and orbit). We found support for nine separate anatomical modules in all cases: phyllostomids as a group, other noctilionoids as a group, and in each dietary class (frugivores, non-phyllostomid insectivores, phyllostomid generalists, and nectarivores). Each biomechanical and sensory module is unique, and their relative strengths and inter-module correlations are unique within noctilionoids, phyllostomids, and within each dietary class. We found that integration among modules tends to be lower in phyllostomids than other noctilionoids. We also found that the rates of evolution of the modules differed from one other and across dietary classes. While the number of modules is conserved across noctilionoids, the re-organization of biomechanical and sensory modules appears to have played a key role in the evolution of phyllostomid bats.

The Grumpy, Lazy Bat Hypothesis: Does White-nose Syndrome Select for a Behavioral Change in *Myotis lucifugus*?

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Wildlife populations can experience rapid phenotypic evolution if human impacts cause major mortality. White-nose syndrome (WNS), an invasive fungal disease, is devastating North American bat populations in one of the fastest declines ever observed for mammals. Traits favoring WNS survival could, therefore, be under selection in remnant populations. Animal personality traits, like sociability and explorative tendency, can affect pathogen transmission and may affect energy balance, which in turn may influence WNS survival. We tested the hypothesis that WNS selects for reduced activity and sociability in bats because reduced values for these traits reduces energy expenditure and/or risk of pathogen exposure. We conducted this study in central Manitoba, Canada where mortality from WNS was first confirmed in 2017. During the pre-hibernation period (August) in both 2014 (pre-WNS) and 2018 (post-WNS), we captured *Myotis lucifugus* and used Y-maze (n = 90 bats) and hole-board tests (n = 77 bats) to assess sociability, activity, and exploration of individuals. In contrast to our hypothesis, we found that post-WNS bats were more sociable than pre-WNS bats. However, as we predicted, post-WNS bats were less explorative than pre-WNS bats, which may reduce their risk of acquiring the WNS pathogen. While we cannot rule out behavioral plasticity as an explanation for our results, personality traits are repeatable in bats and heritable in other taxa, which suggests these differences could reflect an evolutionary change. Our results have implications for the social evolution of bats and for the design of management strategies that aim to facilitate bat population recoveries.

Winter Activity Patterns of Non-cave Hibernating Tri-colored Bats

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Cave and mine hibernating tri-colored bats (*Perimyotis subflavus*) have experienced precipitous declines from white-nose syndrome (WNS). However, tri-colored bats use tree cavities, bridges, culverts, and foliage during winter throughout parts of their range. Our objective was to determine environmental and biological factors that predict activity patterns of non-cave hibernating tri-colored bats during winter and relate them to WNS susceptibility. From November to March 2017-2019 we used temperature-sensitive transmitters to document activity patterns of tri-colored bats in south-central South Carolina, an area devoid of caves or mines. In addition to three bridge roosts, we tracked individuals to 24 tree roosts. We found that the probability of activity increased with ambient temperature and bats maintained a non-random arousal pattern with a high probability of arousal near dusk throughout winter. One-third of all recorded bat days contained an arousal overlapping nighttime. Of these nighttime arousal events, 71% involved activity away

from the roost and 38% resulted in a roost switch. When bats aroused, the probability of activity away from the roost was greater in bridge roosts than tree roosts, increased with body mass, and increased with the previous day's mean vapor pressure deficit. We also found that season best predicted a switch between day roosts, with the greatest probability of switching occurring in early and late winter. Our results suggest non-cave hibernating tri-colored bats assess ambient conditions before arousing and might exploit ideal conditions for foraging opportunities. Therefore, non-cave hibernating tri-colored bats might be less susceptible to WNS than cave and mine populations.

Interspecific Variation in the Heat Tolerance and Evaporative Cooling Capacity of Bats with Differing Roosting Habits

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The majority of physiological research on small mammals has focused on coping with cold. However, given the predictions of climate change models, understanding how small organisms cope with heat is important. Using respirometry in the manner employed for arid zone birds, we estimated heat tolerance and evaporative cooling capacity of insectivorous bats. We predicted that the ability to cope with higher ambient temperatures (T_a) would reflect the nature of roost sites, with species using external roosts (hoary bats) having more tolerance and cooling capacity than bats using cavity roosts (little brown and silver-haired bats). Our data were collected in summer 2018 in Cypress Hills Provincial Park, Saskatchewan, Canada. Gas exchange measurements were conducted the day after capture using open flow-through respirometry at a range of T_as (~ 30–48° C in 2° C increments). Maximum T_a was reached before bats became hyperthermic ($T_{a,\,HT}$) and was significantly higher in hoary (46.5 ± 2.1° C) compared to little brown bats (44.1 ± 1.6° C). The $T_{a,\,HT}$ of silver-haired bats (45.3 ± 1.5° C) did not significantly differ from the other species. Our findings are consistent with predictions as the species that used exposed roosts had the highest heat tolerance.

Landscape and Microclimatic Drivers of Roost Selection in *Rousettus aegyptiacus* Across Southern Nigeria

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The Egyptian fruit bat (*Rousettus aegyptiacus*) is an obligate cave roosting species in Nigeria. The species is ecologically and economically important in southern Nigeria, where it is threatened by habitat loss (due to agriculture) and intense hunting, where offtakes can reach 4000 bats per hunting effort at a single cave per day. Despite having disjoint distribution due to cave-dependence and limited cave availability, knowledge of roost selection is poorly understood. Cave microclimatic condition, landscape effects, and human disturbance are known to influence roost selection in other cave dwelling bats. Therefore, unraveling the influence of cave microclimate, landscape effects, and human disturbance on bat abundance is critical to understanding roost selection in *R. aegyptiacus*. We assessed bat abundance at cave roosts by conducting emergence counts across localities in southern Nigeria. We measured cave microclimate and dimensions, vegetation structure at cave entrances and recorded presence of water. Using high resolution landcover data, we calculated proportion of major land use/landcover types: forest, farmland and bare rock at multiple spatial scales. To understand the drivers of roost selection, we will model the relationship between *R. aegyptiacus* abundance, and cave microclimatic conditions, surrounding vegetation and landscape factors. The results will aid understanding of roost selection by an intensely hunted obligate cave roosting species in both native habitats and human modified landscape. The results will inform cave prioritization for the species conservation.

Seasonal Changes in Diets of Tropical Bats Revealed by Multi-tissue Stable Isotope Analysis

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Seasonal changes in temperature and precipitation in the tropics drive many biological processes. When food resources become scarce, animals may move to areas with greater resource abundance, reduce metabolic activity (i.e., use torpor) or switch to other available (though perhaps less efficient) resources. Stable isotope analysis of animal tissues can be used to track temporal variation in diet of individuals and/or populations by repetitive sampling of a single tissue type. However, the sampling of multiple tissues with different periods of dietary integration can be used to reconstruct past diets within individuals. In this study we sampled multiple tissues from individuals of Neotropical and Paleotropical bat species representing different trophic guilds and foraging ranges. Examining variation in stable nitrogen isotope ($\delta^{15}N$) values among tissue types allowed us to monitor changes in dietary niche breadth. We found more variance in tissue $\delta^{15}N$ among individuals with larger assumed foraging ranges than those of smaller foraging ranges. Additionally, we found a significant effect of period of capture on the pattern of $\delta^{15}N$ in different tissues across several species. Frugivorous bats had similar patterns of shifts in $\delta^{15}N$ throughout the year, whereas insectivores were more variable. There were no significant differences in isotopic niche breadth inferred from different tissues. Using multi-tissue stable isotope analysis is a beneficial way to assess individual and population level variation in diet and may be a valuable technique as it requires fewer sampling periods than other techniques to assess year-round diet in bats.

European Free-tailed Bats Use Wind Regimes to Fly High and Fast

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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.

Too Many Viruses

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Bats are natural reservoirs of a wide variety of viruses, despite many of these bat-borne viruses can cause diseases in other mammals, it seems that health and fitness of bats is not reduced or affected by an evident viral disease. These observations had led to the hypothesis that bats might possess a unique and extremely variable immune system, resulted from a co-evolutionary process between bats and viruses. The main objective of this work was to identify which families of viruses are been expressed in the liver of our species, in this sense RNA was extracted and sequenced with RNA-seq technology from liver samples of fifteen individuals classified in five distinct families of southern Mexico. Bioinformatics analysis revealed sequences of at least ten virus families of DNA and RNA type, being Flaviviridae, Herpesviridae, and Arenaviridae the most frequent. Assembled contigs were homologous to functional viral transcripts or protein sequences, which are essential for retrovirus replication, suggesting that these viruses were replicating in the species at the moment of capture. Our results suggest that at least two species of bats have been under chronic liver inflammation produced by Hepatitis-C like virus, increasing the risk for developing liver cancer.

On the Diversification of Afrotropical Bats

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The radiations of Afrotropical bats remain poorly known, obscured by grossly inadequate genetic and geographic sampling. Our recent efforts to resolve these shortcomings with fairly dense sampling at least in Eastern and Southern Africa have resulted in preliminary phylogenetic and phylogeographic analyses of *Rhinolophus* (Rhinolophidae), *Hipposideros, Doryrhina,* and *Macronycteris* (Hipposideridae), *Nycteris* (Nycteridae), *Otomops* (Molossidae), *Miniopterus* (Miniopteridae), and *Scotophilus* and *Myotis* (Vespertilionidae). Each has included 'species delimitation' analyses to identify evolutionarily independent lineages using multiple independent loci (4-6 nuclear introns) and a range of priors with BPP. Our studies offer clarity on the phylogenetic positions of Afrotropical clades within genera that are distributed across the Paleotropics and beyond. Most genera show evidence of endemic radiations, deep divergences and cryptic, apparently unnamed clades. Recurring patterns of phylogeographic breaks help to identify geomorphic features that promoted historical disjunctions. Yet reliably naming the evolutionarily distinct lineages we have identified will require extensive integrative taxonomic efforts to identify congruent patterns in the differentiation of external, cranial, dental and bacular morphologies, as well as documenting their vocalizations and ectoparasites. A profusion of 19th and early 20th names (sometimes based on fragmentary or poorly described material and many now considered synonyms) must each be evaluated before the cryptic lineages can be given dependable binomials. A recent appraisal that Africa is home to only 221 species of bats may underestimate its true diversity by 50%.

Winter Ecophysiology of North American Desert Southwest Bats

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To help predict potential impacts of white-nose syndrome (WNS) on currently unaffected populations, we launched a study focusing on the hibernation ecology and physiology of desert-adapted bats in Arizona. Our specific objectives are to: (1) describe the presence and abundance of various bat species in AZ hibernacula using visual inspection and photographic documentation, (2) describe the use of shallow and prolonged deep torpor using temperature transmitters, (3) determine total length of hibernation in a given winter using passive acoustic monitoring, (4) measure relative amount of winter energy expenditure (as decline in whole-body fat content) using an EchoMRI unit, and (5) describe winter activities outside of hibernacula that may be related to foraging behaviors, also using passive acoustic monitoring. In winter 2018/19, we completed multiple visual inspections with photographic documentation of bats across three sites, attached temperature-sensitive transmitters to two individuals from two species (*Corynorhinus townsendii* and *Eptesicus fuscus*), collected acoustic data at the three sites from October through April, and estimated pre-hibernatory fat content in 15 individuals of 6 species and post-hibernatory fat content in 12 individuals of 4 species. Very small hibernating populations (maximum n=24) and only solitarily roosting individuals were observed, with a single exception to the latter. Results from the first year of this study will be discussed, as well as methodological modifications we will implement during winter 2019/20.

Changes in Summer Bat Activity Following the Invasion of White-nose Syndrome in Nova Scotia

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Millions of bats in North American have been reported dead at overwintering sites as a result of a fungus, *Pseudogymnoascus destructans*, that causes White Nose Syndrome (WNS). In Nova Scotia, Canada, the fungus was first detected in 2011 and resulted in an average decline of 93% at five hibernacula during 2012-2013. The impact of the disease away from hibernacula is not well-known and is an important link to understand how winter mortalities affect summer population activity and abundance. We compared acoustic data from the summers of 2005-2006 to resampling in 2018-2019 at the same habitats and sites. We predicted a dramatic decline in bat activity for non-migratory species and no significant change in migratory species activity. Acoustic monitoring was conducted along 88 forested rivers in southwest NS covering an area of ~22,000 km^2. Each site was monitored for six nights between 2005-2006 and resurveyed during 2018-2019. We recorded >1,000 detector nights to compare changes in magnitude of bat and species activity from pre to post invasion of the fungus. Our results will be used to assess if the change in summer activity levels reflects the WNS-related decline observed at hibernacula to inform recovery potential of WNS-affected species.

Molecular Adaptations Underpin Dietary Diversification and Specialization in Neotropical Leaf-nosed Bats

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The molecular adaptations underpinning dietary specializations are poorly understood. Among mammals, the bat family Phyllostomidae (New World leaf-nosed bats) has undergone extreme diversification linked to diet, with different lineages specializing on fruit, nectar, insects and blood. To determine whether these evolutionary transitions have involved molecular adaptation in different sets of

loci and pathways underpinning metabolism and morphology, we performed genome-scale screens across 66 bat species. We find that genes under selection in branch leading to the ancestral phyllostomid encode proteins with diverse roles in carbohydrate, protein and lipid metabolism, consistent with adaptation for a generalized diet. At the same time, we detect surprisingly little subsequent selection in the branch leading to frugivores, but a second burst of molecular adaptation for carbohydrate metabolism in the nectar-feeding bats. Vampire bats, on the other hand, show strong selection for the excretion of waste products. Our findings open up new opportunities for studies of metabolism in bats and other mammals.

Predicting Foraging Strategies from Morphological Traits in *Myotis*

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The genus *Myotis* is found on every continent except Antarctica and comprises three primary ecomorphs with different foraging strategies (i.e. aerial hawking, gleaning, and trawling for aquatic prey). Despite striking morphological similarities within ecomorphs, recent molecular phylogenies have shown that these groups are not monophyletic. In this study, we investigated which morphological traits of *Myotis* bats show convergent evolution across lineages, and used morphological trait data to attempt to predict foraging strategies. 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 the L1OU package 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 are ear length, tibia length, and foot length. Ear length may play a role in 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.

Establishing Provincial-scale Bat Monitoring in British Columbia in Advance of White-nose Syndrome

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White-nose syndrome has not yet been detected in British Columbia (BC), but it's devastating effects may be imminent. Wildlife Conservation Society Canada is aiding in disease surveillance, mitigation, and future recovery efforts in BC through two parallel projects: North American Bat Monitoring Program (NABat) and BatCaver. In collaboration with the BC government, we have catalogued baseline bat diversity and relative abundance in 51 grid cells. A network of trained biologists deployed two to four stationary acoustic recorders and conduct two driving transects in designated 10 x10 km grid cells between late May and early July each year. As of summer 2019, we have collected four years of baseline data, expanding the NABat sampling effort each year. Using paired data collected by stationary acoustic recorders and driving transects, we compare the effectiveness of both methods at estimating species distributions. Additionally, we examine whether a strategically collected passive dataset analyzed using an activity index metric can estimate relative abundance with lower variance than the driving transect method. Through our BatCaver program, cavers have also identified and described winter hibernation sites in Western Canada. Capitalizing on caver expertise and geographic knowledge since 2013, we have collected reports of bat sign in over 175 caves and mines, and deployed acoustic recorders paired with environmental

data loggers in known and suspected hibernation sites. We have identified microhabitat features and cave/mine characteristics that are most associated with the caves and mines used as hibernacula in Western Canada.

Female Vampire Bats Vary in their Cooperativeness towards Strangers

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Although cooperation is common across animals, plants, and fungi, individual differences in cooperativeness can make it difficult to predict if and to what extent two individuals might cooperate. Female vampire bats form stable, cooperative food-sharing relationships with both kin and non-kin, and these relationships develop at different rates due to individual variation in co-roosting and allogrooming behavior. Although it appears that some individuals may be more likely to cooperate than others, the cause of this remains largely unknown. To address this problem, we rigorously tested whether there is consistent inter-individual variation in cooperativeness among female vampire bats. We first measured individual rates of allogrooming and food-sharing using video footage of 70 female vampire bats captured from three different populations and tested in captivity. However, because cooperation depends on the identity of both the actor and receiver, we also determined individual variation in rates of allogrooming and food-sharing towards strangers that were introduced through forced association (n = 56). To test factors which might explain why bats differ in their propensity to cooperate, we measured kinship, age and/or age category, and urinary oxytocin, a hormone commonly associated with affiliative social behavior. We detected individuality in cooperativeness, and foresee that our findings will shed further light on the importance of individual variation in the evolution of cooperation. This work lays the foundation for future research that seeks to comprehensively quantify the causes of individuality in cooperativeness.

The National Response to White-nose Syndrome in 2019

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White-nose syndrome (WNS) has been a fixture in research and conservation efforts for North American bats since its discovery in 2007. The causative fungus, *Pseudogymnoascus destructans,* is now present in at least 37 states and 7 provinces in North America, where at least 12 species have been confirmed with the disease and 8 others identified bearing *P. destructans* without disease. Framed by sister national plans in the U.S. and Canada, the community of scientists and stakeholders have propelled comprehensive preparation and response actions to address research and management needs for WNS. The U.S. Fish and Wildlife Service is the lead federal agency coordinating the response in the U.S., and from 2008 to 2018 the agency has provided $34 million to researchers, conservation organizations, and state and federal agencies to address WNS. Our investigation of this disease is advancing our understanding of the life history and ecology of cave microbes, the dynamics of fungal infection and transmission, and bat hibernation physiology and ecology as we search for ways to control *P. destructans* and conserve native bats. In 2019, the Service offered funding opportunities for state-initiated management actions, priority research needs, development of treatments for WNS, and innovative ideas to reduce the impacts of WNS. The working groups of the WNS National Plan continue to advance national efforts including guidance for disease surveillance and diagnostics, decision frameworks for management, resources for monitoring bat populations, and outreach materials in support of national priorities.

Working Towards Reliable Range-wide Status and Trend Analyses using NABat Monitoring Data

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North American bats face unprecedented risks from continuing and emerging threats including white-nose syndrome, wind energy development, and habitat loss. Based on local monitoring efforts, many species of bats are thought to be experiencing unparalleled population declines. However, local observations at known roosting sites or high-quality habitat may not be indicative of species status and trends across larger spatial extents (e.g., across the entire range of a species). The North American Bat Monitoring Program (NABat) aims to provide reliable information on the status (e.g., distribution, activity, local abundance) and trends (changes in these measures) of all 47 species of bats shared by the U.S., Canada, and Mexico. NABat seeks to improve the state of conservation science for bats by providing standardized protocols and facilitating cross-boundary agency coordination and sharing of limited resources. NABat will provide managers and policy makers with information they need to effectively manage bats, detect early warning signs of population declines, assess species vulnerability to potential threats, and measure recovery. Since implementation in 2015, acoustic and colony count data have now been collected in more than 40 states and 10 Canadian provinces. Some of these data are already being used to determine species distributions and population trends. I will present on the current state of the NABat program including efforts to compile acoustic and colony count monitoring data. I will highlight both ongoing and completed analyses and discuss how NABat plans to share this information with the broader scientific and conservation communities.

Acoustic Bat Survey of Santa Rosa Island

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The Channel Islands National Park encompasses five islands. Santa Rosa Island is the second largest of all the islands. It contains over 53,000 acres of sandy beaches, open grasslands, steep canyons, and is home to a variety of species that are endemic to the island. After 154 years of ranching and sport hunting, Santa Rosa Island is in the process of returning to wilderness. Because bats are an indicator species of ecosystem health, an understanding of how the island's bat populations change over time will shed light on the island's recovery. The island's rugged environment limits what people know about the bat populations. Currently, the *Myotis californicus* is the only species that has been physically vouchered on the island, though mammalogist expect up to eight species to inhabit the island. We describe the start of a long-term effort to use active detectors to find foraging bats, placing passive detectors strategically in foraging areas, and using machine learning to identify the species of bats our detectors record.

Miniaturized Proximity Sensors Reveal Evidence for Maternal Guidance in Common Noctule Bats

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How do naïve juvenile bats learn where to roost and where to forage? The use of social information from informed adults is an often-discussed mechanism for the acquisition of knowledge on the whereabouts of such crucial resources during the early life of a bat. The maternity colonies of bats of the temperate zones where females communally rear their young create ideal conditions to answer this frequently asked question. However, studying social information transfer in wild bats is difficult with traditional tracking techniques due to the small body size of most species. We developed a novel 'next-generation' proximity

sensor system (BATS) with animal-borne tags small enough to study medium sized bats and their offspring. By tracking the associations of juvenile-adult pairs, we found evidence for maternal guidance during switching roosts but not during foraging. The guided roost-switching behavior provides evidence for a form of maternal care that has long been assumed, but never documented. Brief and infrequent meetings of juveniles with other tagged bats during foraging were best explained by local enhancement. We did not find any evidence that mothers guide their young to foraging sites. Our study shows how recent technological advances in biologging provide researchers with means to answer longstanding questions in behavioral biology.

Torpor-assisted Migration: What's Good for the Lasiurine is Good for the Myotid

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Many animals undergo seasonal migrations, both long and short. Several temperate zone bats are either long distance or regional migrants, but both must contend with fuel acquisition and conservation for this energy-demanding endeavor. Recently it was found that long distance migrating silver-haired bats use torpor-assisted migration. To determine if the regional migrant Indiana bat also engages in this behavior, we used temperature sensitive radio transmitters to track female spring migrating individuals from hibernacula toward summer grounds and collected ambient temperature (T_a). We created an algorithm to determine when bats were in torpor, warming, normothermic, or cooling. We then used decision tree analysis to predict physiological state based on T_a and diel condition. T_a was significantly warmer when bats were normothermic than when they were in torpor or when they were cooling, but there was no significant difference between any other bat temperature (T_{sk}) and T_a combinations. The nighttime T_a threshold for physiological state was 9.8°C: there was an 87.7% chance bats were in torpor below this temperature. The daytime T_a threshold was 23°C: there was a 96.3% chance bats were in torpor below this temperature. We concluded that Indiana bats used torpor-assisted migration. During conducive weather, bats entered torpor during the day to conserve fuel, foraged before migrating, traveled and foraged throughout the night, and foraged before roosting. In inclement weather, bats warmed but did not emerge and then returned to torpor. Understanding how weather affects migrating bats can provide information about when bats are active on the springtime landscape.

Remarkable Variation in the Diet of *Noctilio leporinus* in Puerto Rico: The Fishing Bat Turns Carnivorous

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The bat *Noctilio leporinus* is common throughout the West Indies, where it is known to feed on fish and insects. Anecdotal observations in Cuba suggest that this bat could prey on other species of bats, at least when they are kept together in captivity. We set out to examine the diet of this species at three caves along the northwestern part of Puerto Rico, namely: Amador Cave in Camuy, and Ventana and Matos Caves in Arecibo. Six guano traps were set under roosting sites of *N. leporinus* once a month. Traps were left overnight and fecal remains recovered were examined in the laboratory under a dissecting microscope. Our results indicate that, in addition to insects and fish, *N. leporinus* in northwestern Puerto Rico is preying on other species of bats. Three species of bats have been recovered under the roosts of *Noctilio*. It appears that this behavior is more common during the breeding season of fruit-eating bats, when *Noctilio* seems to prey opportunistically on the young of these other species.

Hurricane Mediated Extirpation of Bats from the West Indies

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Small islands within the Antillean arch are likely to represent an open system, where reinvasion may be the key ingredient to resilience of its bat fauna. We set out to do a long term survey of Culebra Island. Culebra remains as the least studied island within the Puerto Rican bank, which in addition includes Vieques, St. Thomas, St. John, Virgin Gorda, Tortola and Anegada. Three species of bats have been reported from Culebra. We monitored bat activity, both acoustically and with mist nets, over a total of 20 nights from February 2018 through August 2019. Our results suggest that the only species of bats remaining after hurricanes Irma and María, that hit the Island in 2017, are *Noctilio leporinus* and *Molossus molossus*. The fruit-eating bat, *Artibeus jamaicensis*, appears to be extirpated from the Island, or its population is so greatly reduced that we could not find any evidence of its presence. Most of the fatalities caused by hurricanes among frugivorous bats on the Greater Antilles is due to starvation after the event, since typically caves provide adequate refuge during the hurricane. By and large, the Virgin Islands lack these refuges, a fact that combined with their smaller size may contribute to the periodic extirpation of local populations of bats. As the frequency and intensity of hurricanes increases, this could pose an important factor determining which species survive on these islands.

Urban Tree Roost Use by Evening Bats in Texas

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Bats spend a majority of time roosting and do so in various natural and anthropogenic structures. Our objective was to determine roost selection of evening bats (*Nycticeius humeralis*) on the Gulf Coast of Texas, a widely distributed species on the southern edge of its range. From June to July 2018 and 2019 we mist-netted and radiotracked bats in a protected bottomland hardwood tract located near an urban area. We then compared roost trees with assumed non-occupied trees in the bottomland tract. Seven bats were tracked to five different tree roosts, all within a <1-km^2 area of an urban neighborhood. Colony size ranged from approximately 16 to 500+ bats. Bats selected for taller, larger live oak trees (*Quercus virginiana*; height: 27–31 m; dbh: 108–201 cm) with less surrounding canopy cover and understory vegetation (all $P < 0.0001$). Bats were utilizing protected areas for foraging yet roosting in urban neighborhoods. All bats stayed in roosts for the full life of the transmitter (5–21 days) and no roost switching occurred. The preservation of large trees in urban areas has created bat roosts and allowed a population of evening bats to thrive. These findings may help guide management to prevent decline of common bat species. Roosts could continue to be located and documented by the public with minimal training and lead to long-term monitoring of bat roosts, year-round, through citizen science. Park managers should aim to create more roosts by allowing the growth of large trees, while keeping understory clutter at a minimum.

Is Reduced Thermal Sensitivity in Distal Wing Muscles a Functional Adaptation to Bats' Unique Wing Morphology?

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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 ~22ºC, in *Carollia perspicillata* the distal extensor carpi radialis longus muscle (ECRL) operates at ~12ºC 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 (22–42ºC) 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.

Using Long-term Citizen Science Data to Assess Trends in Bat Populations in Northwest Ohio

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Citizen science efficiently gathers data and increases public knowledge of and interest in research, especially for unpopular species such as bats. We developed a citizen scientist program in 2011 to annually acoustically sample bats in three parks in the Oak Openings Region of northwestern Ohio, which is a major biodiversity hotspot and critical habitat for eight bat species. Volunteers walked trails in Oak Openings Preserve, Wildwood, and Secor parks. Each park was surveyed once a month from June to August. We found differences in bat activity and species richness across locations, species, and survey years. Oak Openings Preserve is the largest park with the widest range of habitats surrounded by agriculture and rural development and had the highest average bat activity (268 calls). Wildwood had the highest species richness as a result of having extensive forest cover and serving as a refuge for adjacent urban areas. Species richness decreased in Oak Openings Preserve and Secor between 2011 and 2018 (respectively from 8 to 7 and from 8 to 6), coinciding with the establishment of white-nose syndrome (WNS) in Ohio, with richness in Wildwood remaining steady. The total number of calls went down in all parks in the 2011 to 2018 period, suggesting an overall decline in bat activity over time, attributable to a combination of habitat impacts and WNS. Citizen science is a valuable tool for studying temporal trends, identifying favorable habitats, and creating a long-term data set for conservation of this vulnerable taxa.

Changes in Underground Roosting Patterns to Optimize Energy Conservation in Hibernating Bats

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Non-migratory bats in colder climates use hibernation to survive winter. By reducing metabolic rate (i.e., using torpor), bats can survive winter on stored fat reserves. During hibernation, bats arouse from torpor and may move within the hibernaculum, a process called "internal migration". We hypothesized that internal migration occurs to optimize hibernation energetics, in that bats move to select a microclimate to minimize energy expenditure both by moving to cooler areas of the hibernacula and avoiding areas with large fluctuations in temperature. By measuring the distance each tagged bat was roosting relative to the entrance of the mine as well as the temperature at 5 intervals along the mine shaft we were able to assess the relationship between the two variables. Early in the hibernation season we observed that 62 % of bats were roosting in the warmer, less energy efficient, deepest 50 % of an abandoned mine hibernaculum. Late in the season there was a shift towards the cooler entrance area, thereby decreasing energy demands during the torpid period, with 78 % of bats in the mine roosting within 50 m of the entrance. Although there was

no significant effect of hibernation period (i.e., early vs late winter) on the number of bats in huddles, the largest huddles occurred close to the entrance at the end of hibernation season. To fully understand and manage bat populations it is important to understand that hibernation is a dynamic process with bats moving and interacting with one-another throughout the season.

White and Clear Wings in Bats

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White and clear wings are distinct features in about 30 species of tropical insectivorous bats (Mammalia: Chiroptera) belonging to three families (Emballonuridae, Molossidae and Vespertilionidae). Such wings may provide camouflage against the sky at dusk and dawn, when bats commute to and from the roost and are vulnerable to aerial predation from birds. We tested this hypothesis by comparing the contrast of black, white and transparent plastic models against the evening sky. Whitish wings indeed reduce the contrast compared to normally dark wings. They may also prevent overheating and therefore facilitate earlier evening emergence, thereby increasing the availability of crepuscular or diurnal insects for food. Whitish wings become maladaptive near artificial lights, where they are highly visible when illuminated against the dark sky. Pale but colored (not whitish) wings and reticulated patterns on translucent wings in some African and south Asian bats may be variations on the same theme, functional as camouflage against a lit background of vegetation and shades.

Using DNA Barcoding to Determine Community Structure of Bat Ectoparasites in Atlantic Canada

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Bats can be parasitized by a variety of ectoparasites, including mites, fleas, and flies. These ectoparasites may be a health concern for the bats as they may adversely affect body condition and therefore have fitness consequences. Many bat ectoparasites are host specific or limited to a group of closely related bat species while others such as *Cimex adjunctus,* the eastern bat bug, are generalist parasites. More research is needed to determine the diversity and number of ectoparasite species in North America and the hosts and ranges they inhabit. Ectoparasite diversity and community structure likely varies between bat species based on roosting strategies of the bats and parasite diet. Previously collected ectoparasites from throughout Atlantic Canada were identified using morphological characteristics and DNA barcoding for the mitochondrial COI gene. Specimens with a variety of collection dates going back 16 years were sent for sequencing at the Canadian Centre for DNA Barcoding. Specimens had a sequencing success rate of 85% with 60% of specimens receiving barcode status and were assigned barcode index numbers (BINs). The specimens were assigned to five operational taxonomic units (OTUs), one per morphological identified species except for *Macronyssus crosbyi* specimens, which were assigned to two OTUs. Nine haplotypes were identified for the 48 specimens of *Spinturnix americanus* and three haplotypes were identified for the four specimens of *Macronyssus crosbyi.* DNA barcoding is an effective method for confirming morphological species identifications for bat ectoparasites and for determining geographic population structure and divergence within species.

An Updated Synthesis on the Effectiveness of Operational Minimization to Reduce Bat Fatality at Wind Turbines

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Wind turbines are known to cause bat fatality, with estimates in the hundreds of thousands each year. Therefore, strategies designed to reduce or prevent fatality are important to avoid population level impacts to bat species. Operational minimization, also known as curtailment, has been scientifically proven to reduce bat fatalities at wind turbines. Specific curtailment techniques vary, but all seek to minimize bat mortality by limiting turbine blade rotation during periods of high bat fatality risk (e.g. low wind speeds). We plan to summarize publicly available curtailment studies to determine the overall effectiveness of operational minimization. In addition, we anticipate providing results based on specific curtailment strategies (e.g., wind cut-in speed) and efficacy by on species. Summarizing the efficacy of curtailment strategies in a variety of circumstances, will allow stakeholders to make more informed decisions on the most cost-effective approach to minimize the impact of wind energy on bats. This process will also help identify knowledge gaps and research opportunities to refine curtailment strategies. Furthermore, this synthesis will allow future work to compare curtailment to other minimization strategies, such as deterrents. A better understanding of the efficacy of fatality minimization techniques will allow conservation actions to address specific project conditions, thereby maximizing energy production while minimizing the impact of wind energy on bats.

Personality Variation between Ground-roosting *Myotis leibii* and Raised-roosting *Myotis lucifugus*

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Behaviors that are repeatable across circumstances and time determine an individual animal's personality. Personality and behavioral variation are subject to selective pressures, including risks related to the use of different habitat types. We explored the ecological and evolutionary consequences of habitat selection by comparing the behavior of *Myotis leibii* and *Myotis lucifugus*, two closely related North American bats that display different ecological traits. *M. leibii* often roost in crevices on the ground, while *M. lucifugus* roost in crevices or cavities that are raised off the ground. We hypothesize that ground-roosting bats experience greater variety and risk of contact with potential predators. We predict that this behavior favors bolder personality and more exploratory and active traits, compared to raised-roosting bats. We examined inter- and intra-specific variation in behavior using a modified, 3-dimensional open-field test and quantified the frequency and duration of behaviors such as flying, landing, and crawling. Bats were continuously video-recorded in in 1-hour nocturnal and diurnal trials. We created a-priori mixed models using combinations of individual characteristics and life history traits to select the models that best describe each species. We found that *M. leibii* (n = 18) displayed more exploratory and bolder behaviors on the ground than *M. lucifugus* (n = 29), as well as higher overall activity during the trial. We also found that *M. leibii* displayed crawling behaviors and movements consistent with foraging while on the ground, which is remarkable for a Vespertilionid species. Future research should explore biomechanical adaptations associated with ground-foraging in *M. leibii*.

Bat Biogeography of Saint Kitts and Nevis

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Trade routes through the West Indies transformed St. Kitts into a sugar monoculture with a montane forest core. Since the decline of the sugar cane economy, which officially ended in 2005, the island has been transitioning to a tourist economy and much of the fallow sugar cane land is being converted to agriculture for local use. The tourist industry has increased the amount of infrastructure around the island, changing the landscape, anthropogenic noise, and light pollution on parts of the island. Given this massive land-use change, bat populations and habitat occupation are in flux. However, because Nevis did not rely on a sugar cane economy, yet shares strong biogeographical similarity with St. Kitts in all other ways, we expect the comparison between the two islands to reveal valuable information about land-use patterns and their effect on bat ecology. The last published mammal survey from St. Kitts dates to 2005, which corresponds with the official end of the sugar cane era. Our in-depth resurvey compares inevitable changes in the distribution of bats across these islands over the last fourteen years. We measured bat diversity and abundance using mist netting and roost surveys. The first acoustic monitoring on these islands was recorded and analyzed using an Eco Meter Touch 2 Pro and Kaleidoscope Pro software to provide additional species composition and abundance data. We compared our data with the 2005 data set in order to assess changes to population sizes and roost sites in relation to topographical and anthropological variables.

Seasonal Differences in Nocturnal Habitat Use by Northern Yellow Bats in Coastal South Carolina

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The southeastern Coastal Plain is projected to have one of the largest urban expansions in the U.S. This region also marks the northeastern extent of the understudied northern yellow bat's range. The objective of this study was to understand seasonal differences in habitat use of this species to inform conservation and management. During February-March 2018 we placed Anabat Express acoustic detectors at 36 sites for 6-10 nights in Beaufort County, SC. During May-August 2018 we placed detectors at the same and additional sites for a total of 64 sites. We placed detectors in upland forests, bottomland forests, fields, saltmarsh, and ponds, and characterized habitat and forest structure within the surrounding 0.05 ha area. Additionally, we measured distance to saltmarsh, freshwater ponds, and residential areas. We developed a-priori models based on forest structure and landscape covariates and used occupancy modeling to determine factors affecting habitat use in summer and winter. The top model for summer was forest structure, with higher probability of use at non-forested sites. The top model for winter was landscape resources, with higher probability of use closer to residential areas and farther from saltmarsh. Our results indicate that non-forested areas such as saltmarsh, fields, and ponds are important to this species in the summer when forests are cluttered. Alternatively, in winter when food resources may be scarce in some areas, landscape habitat may be a more important driver of use. These results will assist in development of management plans that account for changing habitat use throughout seasons.

Using NABat to Determine Factors Affecting Overall Bat Activity at Various Spatial Scales throughout South Carolina

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With many bats rapidly declining throughout the US, there is a need to monitor bat populations and their response to land use change. Using the North American Bat Monitoring Program (NABat) guidelines, our goal was to monitor bat activity in South Carolina to aid in management decisions for bat conservation. During the summer of 2019 (15 May to 17 July), we conducted stationary and mobile surveys in 38 100 km^2 cells that were selected using the NABat sampling design for South Carolina. We conducted only stationary surveys in eight cells, only mobile surveys in 13 cells, and stationary and mobile surveys in 17 cells. We surveyed each mobile route on two nights during the designated survey week and set out stationary detectors for four consecutive nights during their designated survey weeks. We examined whether overall average activity varied by physiographic region and white-nose syndrome (WNS) presence and whether activity was related to forest structure. We expected overall activity in the Blue Ridge region to be lower than the other regions and expected activity at WNS confirmed sites to be lower than WNS negative or suspect areas. Also, we predicted average activity to be negatively related to basal area and tree density. However, overall activity did not differ by region nor by WNS presence ($P > 0.05$) and was not correlated with basal area or density. Physiographic region, WNS presence, and forest structure did not appear to significantly influence average bat activity in South Carolina during the summer of 2019.

Diphallia in *Corynorhinus townsendii*

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We describe the first reported case of diphallia in a bat, *Corynorhinus townsendii*, captured during fall swarming at a hibernaculum in northern Utah, USA. Upon examination, we determined that one phallus was functional, as evidenced by production of urine, while the secondary phallus appeared to be overgrown with skin. A review of the medical literature relevant to diphallia suggests that this is a case of pseudodiphallia with a bifid shaft. We hypothesize that this morphological deformity likely has a low impact on the survival of this individual but may act as a physical barrier to copulation. To our knowledge, this is the first reported case of diphallia in bats. This case appears to be that of an unusual member of the species *C. townsendii* that has undergone abnormal sexual development and grew an additional, physically distinct pene. While deformities such as those described are quite rare and could be difficult to observe from small mammals, we encourage other researchers to closely examine the genitals of captured animals to establish the frequency of such deformities in natural systems.

Recovery Plan for Québec's Non-migratory Bat Species: Main Objectives and Ongoing Actions

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White-nose syndrome arrived in the Québec province in 2010 infecting many cave-dwelling bat populations. Since then, it has spread in most areas of the province and important declines in populations of *Myotis* bats species has been shown by inventories conducted in the province. In response to that, the province has implemented in 2014, in accordance with provincial regulations on endangered species, a bat

recovery team. This team is composed of wildlife professionals from regional, provincial and federal ministries, or from local conservation organizations and consulting firms. In May 2019, the team published the Recovery Plan for Québec's Non-migratory Bat Species, which has as a long-term goal to ensure conditions for populations that are self-sufficient, ecologically functional, and mainly spread-out throughout the current air of distribution. To reach this goal, four objectives have been set concerning educating citizens, following the evolution of populations, developing and applying protection or mitigation measures, and knowledge acquisition. A recovery strategy containing thirteen measures and thirty-five actions is proposed. Some actions are already under implementation: education of bat extermination firms, emergence counts using bat watch, mining and wind farm mitigation measures, passively heated bat houses, monitoring bat activity using pit tagging, and habitat selection using Motus technology. Although most of these projects are on the way, preliminary results, success and issues will be discussed. Involvement of the Québec bat recovery team has sparked, since its establishment, a lot of action and engagement. We believe these are good news to share!

Bats of the World: A New Taxonomic and Geographic Database

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The last comprehensive list of chiropteran species published in Mammal Species of the World in 2005 recognized 1,116 bat species. Although this represented a significant increase over previous tallies, known bat species diversity has continued to climb since that time, with ~1,400 valid species now recognized. Similarly, our understanding of the geographic ranges of many species has continued to change with new revisions and inventories. Researchers in diverse fields ranging from evolutionary biology to ecology and conservation need access to up-to-date information on bat species diversity, taxonomy, and geographic ranges to inform research and management decisions. Although definitive published volumes are desirable for many reasons, the modern digital age provides an alternative: a citable online database. With ongoing input from the Global Bat Taxonomy Working Group of the IUCN Bat Specialist Group, we have accordingly launched a new database at www.batnames.org that provides basic information on every valid bat species currently recognized. Long entries are available for many species and include name, authority, citation, common name, synonyms, type locality, distribution, map, threat status, comments, and references. Short entries (including name, authority, citation, and common name) are provided for taxa that we have not yet fully finished revising and updating. We hope to upgrade all of the short entries to long entries over the next year. Once all the original entries have been revised, the website will be updated biannually (April and October).

Body Mass of Pregnant *Eptesicus fuscus* is Diverging with Long-term Exposure to *Pseudogymnoascus destructans*

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Populations of several North American temperate bat species have experienced well-documented declines resulting from exposure to *Pseudogymnoascus destructans* (*Pd*), which causes white-nose syndrome. Effects on less susceptible species are not as well documented, but these bats could see cumulative damaging effects from annual *Pd* exposure, such as females with fewer energy stores to invest in reproduction. To examine if energy stores of persisting, less susceptible female bats is decreasing, we collected summer capture data of *Eptesicus fuscus* from NY and IN between 1994 and 2018. We used a linear mixed effects model to evaluate female mass as a function of year and site to quantify changes to body mass over time. We found no change in average mass across adult female captures between 1994 and

2018 (P = 0.13). Residuals were subject to an interaction between the number of years exposed to *Pd* and reproductive status (*i.e*. pregnant, lactating, post-lactating and nonreproductive). *E. fuscus* mass diverged from the mean (P <0.001), suggesting a growing variation in adult female energy stores with greater *Pd* exposure time. This was driven by increased variation in pregnant female mass (P = 0.009). Chronic *Pd* exposure on less susceptible species could have population level impacts due to the increased variation in pregnant female energy stores. Further investigation within the variation of these data, such as time and relative location of capture, is warranted to reveal the source of this striking variation.

Effects of Hurricane Maria on the Bat Community on the Caribbean Island of Dominica

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In the tropics, hurricanes are an occasional disturbance that can have severe impacts on the structure and composition of biotic communities. As climate change is predicted to increase the frequency and intensity of these storms, it is important to advance our understanding of species' responses to this disturbance to help us predict future impacts and aid in conservation actions. On 18 September 2017 Hurricane Maria, a category 5 storm, struck the small island (750 km^2) of Dominica causing substantial damage to the vegetation across the island. This provided a unique opportunity to assess the hurricane's impact on bat community structure and composition in the Caribbean. I measured changes in diversity, abundance, reproductive rate, body condition, and habitat use using data I collected during mist-netting surveys prior to Hurricane Maria (2016 and 2017), and after Maria (2018 and 2019). Nine species (750 individuals) were captured in the two years prior to the hurricane, with reproductive females documented for eight species. Nine species (79 individuals) were captured post-hurricane in 2018 and six species (86 individuals) in 2019, with reproductive females documented for seven species across the island after Maria. A decline in the number of captures and percent of reproductively active females of several species indicates varying responses within foraging guilds. Preliminary results suggest a stronger sensitivity for frugivores, and a failure to reproduce post-hurricane. Analysis is on-going and further results will be presented.

Elucidating Patterns of Bat Species Occupancy across a Disturbed Landscape in California's Central Valley

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California's Central Valley, one of the most productive agricultural regions in the world, is home to 17 species of resident and migratory bats. The Central Valley ecoregion has been identified as a crisis ecoregion, with many species at risk due to anthropogenic habitat conversion and drought. In response to severe drought, California Department of Fish and Wildlife (CDFW) implemented the Terrestrial Species Stressor Monitoring (TSSM) project and collected baseline occupancy data for bats. We conducted surveys using SM3BAT acoustic detectors at 274 sites spanning the Central Valley in both the driest year on record (2016) and the wettest year on record (2017). The objectives of this analysis were to determine if human land use and drought influence bat occupancy at a landscape level. This data collection effort resulted in the largest bat acoustic survey of the Central Valley with over 3,300 events. Detections were autoclassified using Kaleidoscope software and manually vetted. We fit single-species occupancy models in a Bayesian framework. Migratory species (*Lasiurus cinereus, Lasiurus blossevillii,* and *Tadarida brasiliensis*) contracted their geographic range during the drought, while hibernating species did not (*Myotis lucifugus* and *Myotis californicus*). Further, arid-adapted species (*Parastrellus hesperus* and *Eumops perotis)* expanded from natural open areas into agricultural landscapes during the drought. Primary implications suggest that migratory species may more easily adapt to drought conditions, irrigated agricultural areas may act as drought refugia, and large-scale acoustic studies can serve as an alternative or supplement to capture for acoustically detectable species.

Defining Phenotypic Species Limits in Hoary Bats

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Defining population and species limits is fundamental in biogeography, community ecology, and evolutionary biology. Understanding these boundaries and the environmental factors that shape them can have strong implications also for conservation and taxonomy. Advances in machine learning and statistical cluster analysis to analyze phenotypic and environmental data can provide improved resolution for examining limits in groups that are difficult to sample genetically. Here, we look at hoary bats across the Americas to test the association of phenotypic limits with the environmental features that help maintain them. Sampling for 16 phenotypic cranial characters was performed on 173 individuals throughout the distribution of the three recognized species of Hoary Bat, including all island groups. Niche overlap analysis was performed on 1174 unique locality records throughout the distribution along with climatic data for 19 climatic variables plus elevation. Phenotypic analyses recovered the currently recognized species clusters (*Lasiurus cinereus, L. semotus,* and *L. villosissimus*). While we know *L. semotus* is genetically related to *L. cinereus*, phenotypically it clusters closer to Neotropical groups of Galápagos, Hispaniola, and the mainland *L. villosissimus*, which also are differentiated from each other phenotypically. Niche overlap analyses showed group variation in niche breadth in a manner congruent with the phenotypic clusters. Our study exemplifies the importance of linking environmental and phenotypic information to shed light on species limits. This approach is especially useful for widely distributed species where cryptic groups can result from heterogeneous combinations of biotic, environmental, geographic, and topographic features of the places where they occur.

Ectoparasite Load Effect on Blood Cell Count in Rafinesque's Big-eared Bats

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In Arkansas, roosts for Rafinesque's big-eared bats (*Corynorhinus rafinesquii*) can be variable and consist of bottomland hardwood trees and manmade structures. Due to anthropogenic change a maternity colony in northeast Arkansas has persisted in an area of intensive agriculture, which was previously part of an expansive habitat of bottomland hardwoods. Because a maternity colony in a manmade structure is rare; in July of 2018 and 2019, individuals (n = 41) were sampled from a storage barn and were found to be the hosts for ectoparasites in the family Cimicidae, which contains bat bugs (*Cimex adjunctus*) and bed bugs (*Cimex lectularis*). The ectoparasites on *C. rafinesquii* are understudied. Ectoparasite loads were recorded and parasites were collected in 90% ethanol. In 2019, small samples of blood were taken from a subset of lactating and post-lactating individuals for blood smears. Neutrophils and lymphocytes will be counted to compare neutrophil-lymphocyte ratios that were collected from a subset of individuals. Other immune cell counts were made with the stained slides. Finally, temperature-sensitive transmitters were fitted to a subset of bats (n = 10) to determine how torpor pattern affects ectoparasite load and immune cell ratios. Understanding physiological tradeoffs in this species is important due to their integral role in environmental services.

In-flight Social Calls of Insectivorous Bats: Species-specific Behaviors and Social Call Contexts

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A species' social environment acts as a selective pressure on its communication systems. Bats exhibit a broad diversity of social group size and complexity. Bats could be useful for studying the effects of sociality on communication, however their social calls are poorly understood. Passive acoustic monitoring occasionally captures in-flight social calls. Surrounding echolocation calls can provide information on which species produced the call and the behaviorally relevant context. We used passive acoustic monitoring in Greensboro, North Carolina, to test for species-specific differences in social calling behaviors and the contexts of call types. We identified seven distinct social call types. *Eptesicus fuscus*, *Nycticieus humeralis*, and *Tadarida brasiliensis* differed in production of social calls relative to activity and proportional usage of call types. Shared called types exhibited species-specific differences in call characteristics, indicating the potential for species recognition. Due to substantial temporal clustering, social calls were grouped into temporally independent call bouts. Time of night and bat activity were correlated with the probability of observing a bout. Bouts consisting of solely complex calls were more likely to occur in single species bat passes with foraging buzzes, suggesting these calls mediate foraging interactions with conspecifics. Bouts of solely downsweeps, solely upsweeps, and both downsweeps and upsweeps were more likely to be produced in multiple species bat passes, suggesting the calls may mediate interactions between unfamiliar individuals. Differences in rate of call production and the use of particular call types associated with different contexts suggest that bat species exhibit differences in in-flight social behavior.

Ways of Seeing: From a Bird's to a Bat's Eye View

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In a forested environment, trees provide the vertical scaffold for a larger community and a change to stand structure may affect how habitats are used by bat species. As it has been observed that sympatric bat species spatially partition resources based upon the structural characteristics of a habitat, clutter creation may affect the availability of habitat within an ecosystem for each bat species differently. In the absence of wildfire, blown-down trees become a primary source of new clutter and to investigate the effects we cut a single tree at six locations along a stream to simulate clutter creation in structurally similar sites where it could be measured. We collected acoustic data at these sites before and after tree-felling as well as in open-canopy and closed-canopy forest stands June 2019 through August 2019. Using three-dimensional point clouds produced from photographs taken of the forest stands with an unmanned aerial vehicle (UAV), we segmented individual trees to quantify structural attributes of the forest stands and the amount of introduced clutter. These data will be used to examine how bat species may respond to changes in habitat availability.

Distribution and Prevalence of *Pseudogymnoascus destructans* at *Tadarida brasiliensis* Roosts in Central and South Texas

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In 2018, the southernmost detection of *Pseudogymnoascus destructans* (*Pd*) was detected on a Mexican free-tailed bat (*Tadarida brasiliensis*) in Central Texas. *T. brasiliensis* are not known to hibernate for extended bouts, and as a result are not expected to be highly susceptible to white-nose syndrome (WNS).

However, because they migrate in large numbers, they may spread the disease further into the western United States and/or south into Mexico, Central and South America. Despite extensive statewide surveys for *Pd*, very little of the previous surveillance effort has focused on *T. brasiliensis*. Texas Parks and Wildlife Department conducted follow up surveys on the previous year's detection of *Pd* on *T. brasiliensis* to better understand the current prevalence of *Pd* in the Central and South Texas *T. brasiliensis* populations. To target the species, iNaturalist and the Texas Natural Diversity Database were queried to find winter roosts across the state. Roosting bats were swabbed and inspected for signs of WNS. Of twenty-three counties swabbed, six counties returned positive for the fungus, including a new southernmost site. Through better understanding the current distribution and prevalence of *Pd* in the Central and South Texas, neighboring states and countries will be better informed for the arrival of *Pd* via this potential vector.

How do Indiana Bat Populations Respond to Forest Management?

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Responsible forest management is a necessary part of wildlife recovery, however, we lack data on effects of management on heath and population sizes of endangered Indiana bats (*Myotis sodalis*). Missouri Department of Conservation established guidelines to minimize risk to Indiana bats while conducting forest management during the maternity season. From 2019–2026, we will be using multiple methods to assess population size and individual health of Indiana bats in 6 conservation areas in northeastern Missouri, 3 with planned timber removal and 3 controls. We captured and attached radio transmitters to Indiana bats at 6 areas 23 May–26 July 2019, tracking bats both pre- and post-volancy and conducting simultaneous exit counts at known roosts to estimate colony sizes. We attached transmitters to 33 of 45 Indiana bats captured, located 39 roost trees, and counted 1–116 bats/area during simultaneous counts. We used Anabat Swifts with directional mics to record Indiana bat echolocation activity at 10 points/area for 5 nights pre- and post-volancy; we will use these data to generate estimates of occupancy and relative abundance for each area. At capture, we measured bats and collected blood, hair, and guano to allow future assessment of individual health via body condition, stress hormones, white blood cell counts, and parasite loads. This 8-year project offers a unique opportunity to test long-held assumptions about Indiana bats' responses to forest management and will inform future guidance on the creation and maintenance of suitable summer habitat capable of sustaining healthy populations of Indiana bats.

Testing Environmental Cleaning Agents to Reduce Contamination of Bat Hibernacula with *Pseudogymnoascus destructans*

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Pathogens with density-independent transmission can threaten the viability of host populations, as pathogen reproduction is not determined by host abundance. One such example is *Pseudogymnoascus destructans* (*Pd*), the fungus that causes white-nose syndrome (WNS), which has devastated bat populations across North America. *Pd* can persist in environmental reservoirs, resulting in density-independent *Pd* transmission and creating potential for host species' extinctions. Treatment of environmental reservoirs could therefore help reduce transmission of *Pd*, and thus, reduce bat population declines from WNS. We tested the efficacy of two environmental treatments for *Pd*: 1) ultraviolet-C radiation and 2) polyethylene glycol (PEG). We delineated circular plots on the walls and ceilings of three *Pd*-positive mines in Ontario, Alabama, and Arkansas (n = 120 plots per hibernaculum). Prior to hibernation onset, we applied one of

four treatments to each plot: UV-C light (254 nm), 28% PEG-8000, 90% isopropyl alcohol (decontamination control), or no treatment (control). We then quantified how a one-time treatment application affected prevalence and load of *Pd* throughout the year, as well as non-target effects on the microbial community, by swabbing roosting substrates at four distinct time points. *Pd* prevalence and load were determined using real-time qPCR and the microbial community was characterized using 16S and ITS2 rRNA sequencing. Preliminary results suggest that responses to treatments were highly site-specific and there were no clear patterns across sites. Our results suggest that site-specific treatments and management responses may be important for reducing impacts of *Pd* on bat populations.

Non-random Association Patterns Reveal Overlapping Subgroup Structure: Evidence for Complex Social Behavior in Little Brown Myotis

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Group behavior is observed widely across the animal kingdom, yet factors influencing group behavior are typically poorly understood. To understand the proximate and ultimate causes and consequences of group formation, it is first necessary to characterize the organization of a group. Little brown myotis (*Myotis lucifugus*) are known to roost in groups that display complex patterns of interactions, described as fission-fusion societies in which groups split and merge through space and time. Here, we apply social network analysis to quantify associations among individuals and begin to test the bat sociality hypothesis, which proposes that bats form groups based on preference for association with specific individuals. We provide evidence of such preferences in association and found that the study population was comprised of multiple subgroups. Interestingly, subgroups showed high connectivity with other subgroups, supporting the presence of fission-fusion dynamics in these systems. We found only limited evidence that group organization was maintained across years, as there was some tendency for associations among individuals to persist across years. The patterns identified are consistent with the bat sociality hypothesis, but future study is needed to confirm that social preferences directly influence these patterns. Our study provides a basis to understand the group organization of a gregarious bat species and future studies should expand the geographic scope of the study, and investigate the intrinsic and extrinsic factors that influence the fission and fusion events that shape this group patterning, contributing to our broader understanding of complex social behavior in mammals.

Movement Patterns of Migratory Tree-roosting Bats During Autumn Migration

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Migration routes of long-distance migratory tree-roosting bats (*Lasiurus cinereus, L. borealis, and Lasionycteris noctivagans*) in North America are poorly understood. Large numbers of bat fatalities recorded at wind energy facilities are contributing to likely population declines of these species. Most documented migratory bat fatalities at wind energy installations occur during autumn migration. There is some urgency to better understand migration patterns of these bats, because like many other jurisdictions, the Province of Saskatchewan plans to dramatically increase wind power generation capacity. We installed passive acoustic detectors in southern Saskatchewan during the migration period to measure migratory bat activity. We placed one set of detectors in a three by three grid pattern across the study area in locations with high wind energy potential and prominent landscape features. We installed a second set of detectors along 5 km transects perpendicular to four of the province's major rivers. We found higher levels of migratory bat activity in the eastern portion of the province. Activity was also generally higher in riparian areas and decreased with distance from rivers. This is consistent with access to resources such as roosting

habitat and water being important in bat migration route selection. Sites located in riparian areas and the southeastern portion of the province contain more forested landscape than other sampling sites located in uplands and grassland ecoregions. Our results will inform siting decisions for future wind energy projects.

Competitors Versus Filters: Drivers of Non-random Structure in Forest Interior Insectivorous Bat Assemblages along Elevational Gradients

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Non-random assemblage structure in species-rich bat assemblages may be driven independently or simultaneously by competition and environmental filtering leading to trait dissimilarity or similarity, respectively. Monotonic decline in bat species richness along forested Afrotropical elevational gradients is resource driven, yet the relative roles of competition and environmental filtering remain unclear. Ecomorphological traits – bite force and wing morphology encode patterns of resource partitioning, but may also respond to environmental filtering, allowing examination of the relative role of competition and filtering. We hypothesize that if mean trait values change with elevation, then competition and environmental filtering simultaneously drive non-random structure of bat assemblages. We trapped bats using five harp traps set every 50 m along four 200 m long transects, at elevational strata ca. 250 – 400 m apart, along two forested elevational gradients in southeastern Nigeria. We measured vegetation structure within four 2 m^2 plots around each harp trap and collected insects using light traps at each transect. For captured bats, we recorded forearm length and body mass, and measured bite force using bite plates attached to a Kitzler force transducer and photographed wings of bats restrained to a gridded board. Wing morphology parameters were measured from photographs of bat wings. We developed regional null communities in trait space at each elevational stratum. We compared mean nearest neighbor distances between species in trait space of observed relative to artificial communities at each elevational stratum. The result of these analysis will uncover drivers of non-random bat assemblage structure along forested elevational gradients.

Bats of Vietnam: An Overview of Research and Conservation

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Vietnam owns highly diverse landscapes with various ecosystems within offshore archipelagoes, coastal realms, and continental regions. It contains different habitats, ranging from flatland with urbanized and agricultural sectors to mountainous and karstic areas with tropical forests. Prior to 1997, bats of Vietnam were poorly studied because the country lacked bat specialist. Since 1998, the author has investigated specifically into the bat fauna of Vietnam with particular emphases on taxonomy, echolocation and conservation. To determine the systematics, echolocation and conservation status of Vietnamese bats, a series of field surveys were conducted through a range of localities in the country. Although the known bat diversity of the country increased impressively over the past decades, many species have been threatened by illegal hunting, habitat loss, and other factors. Several action programs were implemented within selected areas for conservation of threatened species and habitats. The achievements from the surveys and conservation programs include records of species new to the country, discoveries of species to science, resolving the mystery of hipposiderid taxa, findings of special echolocation systems, effective conservation of threatened species, and capacity building. The country is recognized as a hotspot in Asia for bat research and conservation but its central and southern regions with offshore islands are almost unsurveyed. Both academic research and practical conservation actions are required for understanding the bat fauna of Vietnam as well as saving threatened species and habitats in the future.

Persistence of *Myotis septentrionalis* in Suburban Forest Remnants

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Acoustic monitoring since 2015 indicated the presence of *Myotis septentrionalis* within Rouge National Urban Park (RNUP), a newly established urban national park covering almost 80km^2, east of Toronto, Ontario, Canada. Captures in 2018 confirmed the presence of a breeding population of *M. septentrionalis* in one forest located in the south of the park and surrounded by suburbs. In this study we investigated the population, the bats' use of the forest, and their interaction with the surrounding human-made environment. We divided the forest into 500 m grid squares and conducted 10 consecutive nights of acoustic monitoring in each. We attempted to capture *M. septentrionalis* in a subset of grid squares and radio-tracked individuals to identify roosts and foraging movements. We also conducted acoustic monitoring throughout the rest of the park in forest patches larger than 10 ha. We identified acoustic activity of *M. septentrionalis* in all squares surveyed at our primary forest, but recorded negligible activity at other patches within RNUP. We conducted trapping surveys in six squares and captured *M. septentrionalis* in three. None of the tracked bats left the forest during tracking; their foraging activity centered around waterways, while roosts were in mature trees in the forest center. This reproductive population represents a significant record for this species in Ontario, where few observations exist. We conclude that this may be a remnant population, surviving in an isolated habitat patch. This observation demonstrates that *M. septentrionalis* can survive moderate disturbance in habitat fragments within highly urbanized landscapes.

Bat Box Design Affects Microclimate and Suitability as Bat Habitat

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Bat boxes are popular conservation tools, but we know little about how design affects internal microclimate and hot boxes could be ecological traps. We assessed microclimate in 20 box designs, modified by volume, insulation, shading, and airflow, measuring $T_{internal}$ via 12 dataloggers in each box, installed in close proximity and with bats excluded, in central Indiana (mid-May–mid-September 2018). For each design, we calculated proportion unsuitable (>40°C), instantaneous range of temperatures (availability), and daily variation (variability) and, for each position, we calculated the bihourly difference from ambient (ΔT). We measured ambient air temperature (T_a), global radiation (G), and wind speed (*u*) onsite. In a standard design, $T_{internal}$ averaged 26.2°C, but varied from 12–52°C across all positions and days; the top was generally warmest, sometimes with lethal temperatures (≥45°C) in all 4 directions and ΔT >20°C. In the standard, mean availability ranged from 1.4–8.9°C and $T_{internal}$ varied by 3–34.5°C on single days. Other designs varied significantly from the standard and each other in terms of availability and variability. Changing box volume produced large differences; for example, a short box was 7°C more stable than a long box, but the long box offered greater availability (5.3 ± 0.2°C vs. 1.6 ± 0.1°C). Daily maximum T_a and G directly affected box temperatures, while daily maximum *u* had an inverse effect. Box design and weather affect box microclimate, which has important implications for the use of bat boxes as mitigation tools. We recommend examining seasonal design preferences by bat box dwellers.

White-nose Syndrome Fungus Triggers Similar Immune Response in Fibroblast Cell Culture as in Living Bats

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White-nose syndrome (WNS) has decreased populations of some temperate bat species to levels where conducting research on live bats must be curtailed, especially when destructive sampling is required. We reported previously a cell-culture method to assess immune function of bats using fibroblast cells isolated from wing punches, which exposes the cell cultures to the fungus responsible for WNS,

Pseudogymnoascus destructans (*Pd*). Fibroblast from WNS-susceptible species attempt to mount an immune response that is ineffective but likely costs the bat valuable energy. Conversely, fibroblast cells from WNS-resistant species do not show any immune response to *Pd*. However, a key question now is whether the responses to *Pd* of these cells in culture is the same as in the living bat. Because fibroblast cells *in vivo* secrete chemicals to activate the immune system when tissue is injured or infected, we hypothesized that wing punches from bats after hibernating with *Pd* will show the same profile of gene activation as seem in the cell cultures. We have now developed/used quantitative real-time polymerase chain reaction (qRT-PCR) assays to test the activity of several immune genes that were upregulated in the cell-cultures (transcriptomics analysis). Generally, we found that wing tissue from tricolored bats (WNS-susceptible) late in hibernation showed increases in gene expression compared to pre-inoculation with *Pd*, but wing tissue from big brown bats (WNS-resistant) did not change (or decreased). These results, though preliminary, suggest that the cell-cultures may indeed be a good surrogate for using living bats in some kinds of WNS research.

Assessing Microplastic Contamination in Bats and Their Insect Prey

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Plastic pollution has been increasingly recognized as a serious environmental issue, with many potential ramifications to ecological and wildlife health. Microplastics are a type of plastic pollution, and are defined as a plastic particle that is between 1 nm and 5 mm in size. These particles have the potential to bioaccumulate across trophic levels, cause physical blockages in digestive tracts, and may become contaminated with organic environmental toxins or leach “plasticizing" chemical toxins that are present in the plastics themselves. Globally, bat populations have been in decline for decades from a variety of sources, such as human persecution, environmental contamination/degradation, and disease. As many bat species are slow to reproduce, these declines can be difficult to recover from, and the additional stress that microplastic pollution potentially adds may hamper their recovery. Bats may be exposed to microplastic contamination through their diet or drinking water, however to date no studies have been conducted to assess the possibility of such contamination in bats. In order to do so, gastrointestinal tracts of bats as well as guano samples will be chemically digested using wet peroxide oxidation, and analyzed using microscopy and Fourier-transform infrared spectroscopy. Insect samples will be collected using Malaise traps and hand nets and analyzed in the same manner. Concurrent with that, guano samples will also be analyzed to identify DNA of prey items to compare with results from insect sampling, which will aid in identifying specific insect prey as a potential vector of microplastic exposure in bats.

Development of Wind Energy in Guatemala: A Negative Way to Report New Species for the Country

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Wind energy is one of the government strategies used to promote sustainable development using renewable resources in Central America. In Guatemala, there are no specific regulations for this kind of activity, and the magnitude of efforts made to determine the potential impacts varies considerably and depends greatly on each wind energy company. Almost all projects in operation and those in process of acceptance are located in the central region of the country, where Nearctic and Neotropical species converge. In this study, we describe the inconsistencies between pre-operation monitoring that described the bat diversity and post-operation monitoring, which described impacts of wind turbines on bats of a particular wind farm. In the pre-operation monitoring, 19.6% (19 species) of the bat species reported for the country were registered, whereas in the post-operational monitoring the percentage of species increased to 34% (33 species), plus four new species records. This increases the number of species reported for

Guatemala to 101. It is virtually impossible to establish the impact of these findings at the population level, even more when the most affected species has been reported on very few occasions or their existence was previously unknown. These unexpected findings highlight the necessity of designing specific protocols to regulate wind energy in the future and to continue with the efforts to describe the bat diversity of the country.

Real-time Sequencing of *Pteropus hypomelanus* in Vietnam to Generate Genomic Resources and Build Scientific Capacity

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Historical collections in biodiversity hotspots represent some of the best repositories of scientific material, yet access to labs with the most up-to-date genomics equipment makes unlocking the full research potential of the collections difficult. Bringing the lab to the museums solves this problem, while also serving to build scientific capacity for local scientists. *Pteropus* (Mammalia: Chiroptera: Pteropodidae) flying foxes are large fruit bats critical to the natural landscape of Vietnam serving as long-distance seed dispersers and pollinators. However, flying foxes have experienced population declines in the past few decades as foraging and roosting habitats continue to decline in quality as anthropogenic development increases. Of the three Vietnamese *Pteropus* species, *P. hypomelanus* is of greatest taxonomic interest due to its disjunct distribution, poorly known subspecies limits, and understudied genetic diversity. In Vietnam, *P. hypomelanus condorensis* is only found on Con Dao Island in the south, and its relationship to other *P. hypomelanus* remains unclear, despite its potentially high conservation value. Here, we used a portable DNA sequencer, the MinION (Oxford Nanopore), to sequence DNA from tissue samples of historical specimens of *P. hypomelanus* at IEBR-VAST in Hanoi, Vietnam. This method precluded the need to samples to outside sequencing facilities. We reliably produced high quality gDNA without the need for excessive infrastructure or equipment and we developed protocols for bringing real-time sequencing to regional collaborators, dispelling some barriers of unequal access to genomics. At the same time, we were able to answer pressing questions about the genetic diversity of *P. hypomelanus condorensis*.

Morphological Variation and Origination of Chiropteran Wing Membranes

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Bat wings are comprised of several, novel membranous structures that are supported by elongated forelimb and digit bones. The achievement of powered flight in bats led to an unprecedented adaptive radiation and diversification in membrane structure, such that today bats employ diverse flight styles and account for over 20% of all mammalian species. Despite the importance of the evolution of the bat wing to the group's success, the mechanisms that drove the origination and subsequent diversification of the novel components of the wing remain largely unknown. Our research specifically investigates the evolutionary origination and diversification of two novel membranes of the bat wing: the plagiopatagium, which connects the 5th digit to the body and hind limb in all bat species, and the uropatagium, which connects the hind limbs in many species. We seek to determine when during development and from what tissue sources the membranes initially form, and when differences in membrane form arise among species. This is achieved by performing geometric morphometrics on embryonic specimens housed at the American Museum of Natural History (AMNH). Additionally, we establish a general cellular and molecular framework for plagiopatagia and uropatagia development in bats and establish how this framework differs among species with divergent membrane development. This is achieved by visualizing cellular processes,

gene expression, and protein localization in developing embryos. We determined that divergence in wing morphologies occurs later in development via differential timing of cellular proliferation and variation in gene expression.

Drivers of Flying Fox Hunting in Southeast Asia

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Hunting of flying foxes, species of *Pteropus* and *Acerodon* (Pteropodidae), is widespread in Southeast Asia, and threatens 21 of the region's 30 species (IUCN 2019). The primary use of hunted bats reported in Red List assessments is for human consumption (20 species), but this simple explanation does not capture the diverse beliefs and motivations driving hunting behavior, hampering conservation intervention. The goal of our project is to develop, test and distribute a standardized, scientifically sound protocol to study hunting of flying foxes regionally and develop effective responses to conserve flying foxes. Our protocol is intended to both quantify the magnitude and extent of flying fox hunting and characterize factors affecting hunting behavior. The Theory of Planned Behavior provides our conceptual framework, and posits that behavioral intention is predicted by attitude, subjective norms and perceived behavioral control. This is a powerful approach because analysis of the differential influences on behavior can help identify the most important barriers to change and targets for intervention. The protocol was developed and implemented in three areas of intense hunting in Sulawesi (Indonesia) and the Philippines. Here we report and compare our findings across hunting sites. Although all sites shared a positive attitude towards hunting (hunting is a "good thing" to do), they differed in the significance of social norms and perceived behavioral control as well as in specific behavioral, normative and control beliefs. We highlight how our findings are being used to guide pilot conservation programs to reduce hunting.

Bat Wing Skin pH

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Skin is a complex physical barrier and chemical landscape of distinct niches. Skin represents the primary interface between a host and its environment and is the body's first line of defense against pathogens. White-nose syndrome (WNS) is a cutaneous fungal infection of hibernating bats that damages wing membranes, causing physiological disruptions that can lead to death. Cutaneous pH varies with season, sex, age, and species, and may alter pathogen virulence or host susceptibility but has not previously been characterized in bats. To understand how skin pH varies between wing regions and species and how this might alter the "landscape" of the wing, we measured skin pH on the surface of bat wings of different species using non-invasive probes. Female bat skin was more acidic than male skin, and dorsal wing surfaces were more acidic than ventral surfaces. Acidity varied between species and locations. In Ontario, Canada, *M. leibii* were the most acidic ($n = 10$, mean = 6.03 ± 0.13), followed by *Eptesicus fuscus* ($n = 67$, mean = 6.04 ± 0.14) and *Myotis lucifugus* ($n = 251$, mean = 6.23 ± 0.12). Bats were more acidic in New Brunswick than in Ontario (*E. fuscus* $n = 27$, mean = 5.73 ± 0.15; *M. lucifugus* $n = 34$, mean = 5.80 ± 0.15),

while *M. lucifugus* in Prince Edward Island were more alkaline (n = 35, mean = 6.38 ± 0.09). Variation in skin pH may impact the composition and diversity of skin microbiomes on bats and susceptibility to WNS.

A P53 Duplication Influences the Stress Response in the Long-lived Bat, *Myotis lucifugus*

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Cancer is a disease common to all complex life. Many life history traits, such as size and lifespan, are correlated with cancer risk between individuals of a species; however, this correlation does not hold when comparing between species. This phenomenon, known as Peto's Paradox, is resolved as species co-evolve cancer suppression mechanisms alongside increased sizes and lifespans. However, the exact mechanisms involved are largely unknown. Bats represent an ideal clade to study this paradox, as the combination of clade size, phylogenetic diversity, and recent divergence times preserves a detailed record of the genetic changes underlying their diversity in body size and lifespan. We show that the little brown bat, *Myotis lucifugus*, has two full copies of TP53, a central regulator of cellular stress responses; *M. lucifugus* is the only species to-date with such a full-locus duplication. To investigate how these two copies of TP53 influence the stress response of M. lucifugus relative to 4 other closely related bat species (*M. evotis*, *M. thysanodes*, *M. yumanensis*, and *E. fuscus*), we measured apoptosis, cytotoxicity, and viability in primary fibroblasts in response to chemically induced DNA-damage, unfolded protein response, and oxidative stress. We show that both loci are transcriptionally active in tissue RNA-seq and in primary fibroblasts via RT-qPCR, and that knocking down TP53 reduces apoptosis and necrosis in response to DNA damage. These results demonstrate a functional role for two copies of TP53 in mediating the stress response of the little brown bat, *Myotis lucifugus* and resolving Peto's Paradox in this species.

Gotta Catch'Em All! Using PNA-DNA Clamps to Increase Microbiome Read Numbers in a Diet Specialist

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The popularization and further development of sequencing techniques has vastly increased the number of microbiome studies over the past 10 years. Although the actual objectives of these studies vary widely, they always rely on having high microbiome read numbers (MRN) for the bacterial taxa within a sample. We collected fecal samples from 550 lesser long-nosed bats (*Leptonycteris yerbabuenae*) from three different sites along the migratory route in Mexico. We extracted total DNA and sequenced the 16S V4 region from bacterial DNA. The first results showed a high level of "contamination" that was hijacking our reads and consequently greatly affected the MRN. Further exploration revealed that the V4 primer was highly effective in yielding chloroplast and mitochondria sequences. While this is normal in any microbiome study, the disturbing part was an extremely high percentage of the reads assigned to the genetic material of the cell organelles, that in some cases reached 95% of all reads. After recognizing that the contamination came from a high percentage of pollen from the bat's temporary main diet, the cactus saguaro (*Carnegiea gigantea*) present in the fecal samples, we developed species specific PNA-DNA clamps for the cactus organelles. This way we were able to reduce the pollen-derived sequences in the microbiome from 95% to 20%, thus improving the MRN significantly. In the light of more studies exploring the microbiome of different bat species, the use of PNA-DNA clamps can be an excellent option when dealing with dietary specialists.

Movements and In-roost Behavior of the Wooly False Vampire Bat, *Chrotopterus auritus*

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Carnivorous bats represent an ultimate extreme in specialization of bats in the New World. The woolly false-vampire bat, *Chrotopterus auritus*, is the second largest bat in the Americas but little is known about its ecology. We tracked the movements of 10 individuals from 2 colonies on 32 occasions for a total of 72 foraging nights, the largest sample size for any study on *Chrotopterus*. One roost was surrounded completely by undisturbed forest whereas the other was surrounded by deforested habitats used for agriculture and cattle pasture. Using miniature GPS tags, we documented an average home range of 108 ha, a core foraging area of 3.78 ha, and average maximum flight distances of 2.06 km. The bats ranged farther and flew significantly longer distances in from the roost in a relatively more disturbed landscape than on the undisturbed landscape. Males flew longer and more variable distances. Bats used the well-preserved semi-deciduous forest more often than secondary forest and agricultural fields for traveling and foraging, but the bats occasionally moved and foraged along the borders of secondary forest and agricultural fields adjacent to semi-deciduous conserved forest areas. Although this carnivorous bat might cope with some fragmentation, large well-preserved forested areas are highly important for its conservation. We also present the first evidence showing food supplementation in a variety of combinations. Genetic studies are under way to understand the identity of the bat involved.

Impacts of Habitat Conversion by Hyperabundant Moose on Summer Bat Activity in Newfoundland, Canada

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Large herbivores can drastically alter local vegetation structure, subsequently affecting biotic communities. In Gros Morne National Park, Newfoundland, hyperabundant moose populations have exacerbated the conversion of mature forest stands into open meadows: “moose meadows” (MM). This shift in vegetation structure has affected habitat use by other fauna (e.g. songbirds). We hypothesized that bats and insects would use MM differently than they would regenerating or mature forests. We predicted that reduced vegetation in MM habitat would result in lower insect biomass and consequently, lower bat activity. We acoustically monitored bats and collected nocturnal insects during summer 2017 and 2018 from four habitat types ranging from MM to mature forests. Insect activity differed among habitat types ($F_{df=3} = 5.555$, $P < 0.01$), with the lowest mean biomass in MM, but contrary to the prediction, bat activity did not ($F_{df=3} = 0.306$, $P > 0.05$). To further explore drivers of bat activity, generalized linear mixed models were used. Three model sets were generated, each incorporating a different category of explanatory variables– vegetation, environmental, and insect – and compared using second-order Akaike information criterion (AICc). The vegetation model had the best fit (AICc = 1130.6) and suggested that average snag abundance, percent deciduous dominance, bat species interactions with vegetation height classes, and sampling year were the most influential predictors of bat activity. While pre-established habitat designations did not predict variation in bat activity, vegetation structure was important and may still indicate a potential effect of forest conversion by moose on summertime bat activity.

Variation in Bat Use of an Ephemeral Wetland in Western Tennessee

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During the summer months, most species of bats in Tennessee use the forested landscape to both raise their offspring and to forage. We examined the variation in bat use of an ephemeral wetland located in the Beech Ridge Unit of the Obion River Wildlife Management Area June–October 2018 using both mist net and acoustic surveys. We hypothesized that there would be variation in species richness from summer through early fall, and that both the mist net and acoustic surveys would reflect those differences. We netted bats, identified them to species, and collected morphometric data every 3 weeks beginning mid-June. Simultaneously, we used a bat detector near the net survey site to record bat activity and species richness for at least two weeks after almost all net nights. After files were scrubbed for non-bat noise, species were identified, when possible, and bat activity were examined with SonoBat v. 4.2.2. The bat passes identified to species by SonoBat were then manually vetted. During the study, species richness varied by net night and month, and similar variation was reflected in both the net and the acoustic surveys. Eight species were captured either by mist net, by acoustic survey, or by both. All of the species captured via mist net were also captured acoustically, but one species was captured via acoustic survey but not mist net. The variation in bat species assemblages within this seasonal examination of the bat community at this site may have implications for future habitat management strategies.

BatAMP's New Visualization Tool Provides Novel Insights into the Seasonal Ecology of Bats

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Knowing the distributional range of a species is fundamental to understanding its ecology and providing for its conservation and management. Generally, the first level of understanding is based upon static species range maps, which include many historic locational records. However, as species ranges shift due to environmental change, it is increasingly important to base conservation decisions on current areas of occupancy. In addition, many species of bats shift their distribution and activity areas seasonally; something not reflected in conventional range maps. Fortunately, across the U.S. and Canada, acoustic monitoring efforts for bats are generating multitudes of new species occurrence records each year. Increasingly, results from these local research and monitoring efforts are shared to the Bat Acoustic Monitoring Portal (BatAMP) for use in understanding regional- and continental-scale seasonal occurrences of bats. As of July 2019, over 6 million detections of 34 species from 35 states and provinces have been compiled in BatAMP during the years 2006–2018. The recently launched data visualizer (https://visualize.batamp.databasin.org/) provides users interactive filtering capabilities to focus on particular species, geographic extent, and time periods of interest. I demonstrate the use of this tool as it relates to documenting survey effort, exposing potential range extensions, and generating hypotheses about the seasonal occurrences of bats at large spatial scales.

Intra-annual Isotope Sampling of Red Bats in Nebraska Raises Questions

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Wind turbines are estimated to kill hundreds of thousands of bats in North America every year. Reported mortality indicates that long-distant migrant species are the most impacted; with red bats (*Lasiurus borealis*), hoary bats (*L. cinereus*), and silver-haired bats (*Lasionycteris noctivagans*) comprising

approximately 80% of mortality. Because most mortality occurs during the fall migratory period, effective conservation actions rely on information about these movements. Stable isotope analysis increasingly used to infer migratory movements of bats. We used the method in a novel way, focusing on changes in isotope values at one place over time. We captured red bats during the summer and fall of 2016 at one location in east-central Nebraska. We compared the mean and distribution of stable hydrogen isotopes in summer and fall to infer possible migratory timing. For comparison to other studies, we also calculated catchment area of bats using previously published models. No difference in hydrogen isotope values of red bat fur was observed between seasons. Consequentially, mapping catchment areas showed high probability that both summer and fall bats originated locally. Potential catchment areas for red bats encompassed most of the species range, leading to questions about the usefulness of such mapping activities. Additionally, the lack of change in isotope values raises questions about the generally accepted theories about migratory behavior of red bats. Our study emphasizes that caution should be used when interpreting isotope analysis. Fundamental research to understand isotope patterns in bats has not been done as it has with insects and birds.

Insights from Monthly Species Distribution Models for Three Migratory Bat Species Impacted by Wind Energy

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Understanding seasonal variation in the distribution and movement patterns of migratory species are essential to their monitoring and conservation. Bats are a group of species that are migratory, yet, when compared to birds, we know much less about their seasonal distributions or migratory movements. This is significant because of the impact wind energy has on migratory bat populations through increased fatalities. Here we describe more accurate seasonally resolved distributions for the three species (*Lasiurus borealis* [Eastern Red Bat], *L. cinereus* [Hoary Bat], and *Lasionycteris noctivagans* [Silver-haired Bat]) most impacted by wind farms that can be used to make inferences about migratory paths and behavior. To accomplish this, we used 2880 occurrence points collected from the Global Biodiversity Information Facility over five decades in North America. We used five approaches to infer species-specific distribution patterns: regression (GLM), maximum entropy (MaxENT), BIOCLIM algorithm SDM, random forest, and an ensemble. Our results suggest that all three species exhibit variation in distributions from north to south depending on season, with each species showing potential migratory pathways during the fall migration. Additionally, we observe the largest potential for interactions between wind turbines and species distributions during summer months for both Hoary and Eastern Red Bats, while Silver-haired Bats show more potential interactions during winter months. Overall, this study generated inferences of the migratory behavior for three impacted bat species that can be used to minimize the impact of future wind farm locations and for improving the accuracy of biomarker-based assignment studies by providing spatially-based priors.

An Ounce of Prevention: Using Infra-red Technology to Proactively Manage a Bat Roost

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Advances in technology allow improved management of species that historically have been challenging to study and may allow researchers and managers more insight into behavior. We installed an infra-red beam-break system on a Mexican free-tailed bat seasonal roost in central Nevada to monitor roost activity. The system runs continuously and passively and provides data on a daily basis to managers via cellular connection, thus requiring minimal field maintenance. While this beam-break system and the data it provides are instrumental to a nearby commercial wind production facility, the use of this technology has

broader implications. Relying on 6 years of data, we'll provide insight into changes in activity patterns across different scales. Variables, such as weather, which can affect activity patterns, may also be investigated.

Historical Reconstruction of Bat Diets using Stable Isotope Analyses

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Agricultural intensification has been linked with population declines and reduced diversity among arthropods and their predators. In recent history, the Midwestern region of North America rapidly transitioned from a complex, dynamic system to the largely agricultural landscape seen today. To assess whether and to what extent bats may have shifted their diets in response to human-mediated landscape changes, we compared carbon and nitrogen isotopic ratios from little brown and big brown bat tissues collected in Wisconsin and Illinois. Using hair from museum specimens, we measured bulk $\delta^{13}C$ and $\delta^{15}N$ to reconstruct historical bat diets. Additional hair and bone samples from contemporary bats were also measured to calculate seasonal and long-term dietary niche widths. Preliminary results show that for both bat species, historical samples were significantly more enriched in $\delta^{13}C$ than contemporary samples. For big brown bats, historical samples were also significantly more enriched in $\delta^{15}N$. These results demonstrate that bats have shifted their dietary niches over time and suggest that agriculturally-dominated landscapes do not support the main prey base of these bat species.

Nuclear Phylogeography and Distribution Modeling of the Widespread Species Big Brown Bat

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Big brown bat (*Eptesicus fuscus*) is a common hibernating bat distributed across most of North America, several Caribbean Islands, and northern South America. A previous range-wide study of big brown bat populations identified mitochondrial phylogeographic patterns that roughly corresponded to the morphological subspecies and indicated clear geographic divergence. However, the previously generated nuclear structure showed a lack of differentiation, reflecting either sex-biased gene flow or insufficient power of the markers used. Further clarification of nuclear divergence using more powerful markers is thus important for the understanding of population structure and patterns of gene flow. Here we hypothesize that mitochondrial and nuclear genomes have similar population structures shaped by both unbiased contemporary gene flow and historical vicariance among glacial refugia. We used the more powerful SNP data generated by bestRAD sequencing, and we did species distribution modeling (SDM) in MaxEnt to identify historical refugia using Bioclimatic variables on WorldClim and occurrence records on the Global Biodiversity Information Facility. Preliminary results from 96 samples confirmed nuclear divergence among populations in the western US, eastern US, and Caribbean Islands, similar to the patterns of mitochondrial phylogeography. The SDM reconstruction showed that Central America was the main glacial refugia but is faced with a loss of suitable habitats under future climate change scenarios. Our data supported the geographic nuclear divergence and particularly suggested genetic diversity and distinction of populations on the Caribbean Islands, which are proposed to be evolutionarily significant units (ESUs) and a focus of conservation under impacts of climate change.

Genomic, Morphological, and Developmental Basis of Olfactory Evolution in Phyllostomids

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Neotropical leaf-nosed bats (Phyllostomidae) are well known for their dietary radiation and accompanying morphological adaptations for the consumption of new food resources. The evolution of frugivory, nectarivory, and sanguivory from an insectivorous ancestor suggests novel mechanisms of food detection must have also evolved, and behavioral evidence shows phyllostomids strongly rely on olfaction while echolocation is supplemental. When the profound morphological or genetic changes necessary for dietary diversification emerged is unknown, but enable new diets, these changes must precede dietary diversification. We compared the olfactory turbinate morphology (nasal cavity structures in which chemosensory epithelial tissue is distributed), olfactory receptors sequenced from olfactory epithelium transcriptomes, and ontogenetic sequences of turbinate development in phyllostomids with differing diets to test if adaptive selection or novel morphologies occurred in the olfactory system prior to dietary divergence. We discovered: [1] metrics of olfactory turbinate complexity suggest turbinate shapes are highly variable, but have strong phylogenetic signal; [2] gene duplication within particular olfactory receptor subfamilies, but more recent than the evolution of plant-visiting in bats; [3] ontogenetic development of turbinates remains relatively simple earlier in development and the complexity of the structures occurs at very late stages. This is the first study to integrate a synergistic view of the olfactory system in bats, considering the morphological, genetic, and developmental basis of chemosensory diversity.

Land Use Predicts Occupancy of Bats in an Agricultural Landscape

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Bats provide crucial pest control services in heavily agricultural landscapes. However, their populations are vulnerable to dramatic declines due to wind turbines, habitat fragmentation, disease, and climate change. Habitat preferences of vulnerable species must be identified in order to develop appropriate management strategies. To determine habitat preferences, we acoustically recorded bats at 22 sites throughout Dubuque County, Iowa, for 4 nights per site during summer 2018. Calls were identified to species in Kaleidoscope. We gathered site-level data on landscape condition from ArcGIS and weather covariates of detection from regional weather stations. To investigate how weather and landscape variables impact bat detection and occupancy, respectively, we ran single-season occupancy models in Program Presence. We identified 18,399 bat calls, representing all 9 species previously documented. We implemented occupancy models for 4 species (*Eptesicus fuscus*, *Lasiurus borealis*, *Myotis lucifugus*, *Perimyotis subflavus*); the other 5 species were detected too infrequently for reliable modelling. Detection probability of 2 species, *L. borealis* and *P. subflavus*, was impacted by moon illumination and minimum temperature, respectively. Occupancy of all 4 modeled species was influenced by landscape variables. Larger bat species preferred agricultural areas while *M. lucifugus* preferred forested areas, possibly due to prey availability. Only *P. subflavus* avoided urban areas. The larger species and *P. subflavus* avoided areas near rivers or wetlands, which may be explained by correlated geographic characteristics of the sampling sites. Additionally, multiple detections of *M. septentrionalis* and *M. sodalis*, both federally-listed species under ESA, indicate the need to proactively protect bats in Dubuque County.

The North American Society for Bat Research (NASBR) is a society dedicated to the promotion and development of the scientific study of bats (Chiroptera) in all its branches, including conservation and public education. NASBR is a registered 501(c)3 non-profit organization. For more information about the society and contact information visit www.nasbr.org

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