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The Effects of Elevation on Foraging Behavior of Bats in Southern Appalachia

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The Effects of Elevation on Foraging Behavior of Bats in Southern Appalachia

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by

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ABSTRACT

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There are limited studies on bat activity in higher elevations in the Appalachian region. Levels of bat activity were compared in south central Appalachia at low (< 914.4 m) and high (> 1, 524 m) elevations in open, forest edge, and riparian habitats. Additionally, habitat suitability was modeled for a common species, big brown bat (*Eptesicus fuscus).* The study started May 27th 2019, and sites were monitored biweekly until October 2nd 2019. Six species and one genus were recorded during the study. Species from the *Myotis* genus were grouped together because of similar call characteristics. Results show that species were significantly more active in the lower elevations ($F= 44.22$, $p<0.001$, $\alpha=0.05$), than in higher elevations. There was no significance found for bat activity between early, mid, and late summer ($F=0.08091$, $p= 0.922284$, $\alpha=0.05$). The model showed that habitat for big brown bats will contract north by 2050.

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CHAPTER 1. INTRODUCTION

Bat Activity and Elevation

Bats are a critical component in most balanced ecosystems as they regulate insect suppression, seed dispersal, and plant pollination and are therefore considered indicator species (Kunz et al. 2011). Ecosystem services provided by bats are beneficial to humans but are often overlooked (Adams and Pedersen 2013). Moreover, public perceptions of bats can be negative although bats are able to consume many insects or provide seed dispersal and pollination for crops (Adams and Pedersen 2013). Despite their ecological value, the role of bats within their immediate ecosystems has not been thoroughly examined in many regions (Kunz et al. 2011; Adams and Peterson 2013). This includes a basic knowledge of the foraging habitat utilized by various bat species across the eastern United States (Kunz et al. 2011). Such information would allow foresters to implement enhanced management practices that consider the necessary requirements for bat survival. This is particularly important today as bat populations in the eastern United States have been decimated by white nose syndrome (WNS), a fungal infection (*Pseudogymnoascus destructans)* of the skin. White nose syndrome has killed millions of bats since being found in the United States in 2007 (Verant et al. 2014). WNS mainly affects bats that hibernate in caves (Hayman et al. 2016). During torpor, species keep their body temperature <10°C which allows them to survive the cold months on their winter energy reserves. White nose syndrome causes euthermic arousals, which consume most of their limited energy budget (Hayman et al. 2016). Bats affected by WNS usually begin dying after three months of hibernation as the disease causes them to be frequently aroused from torpor which leads to starvation, emaciation, and death (Hayman et al. 2016).

Predicting how bats utilize the landscape and how that affects their occurrence is crucial for conservation (Hirschheydt et al. 2020). Species typically forage in four types of habitats: clutter, forest edge, open, and riparian zones. Some species, such as the big brown bat (*Eptesicus fuscus*), utilize multiple habitat types and do not have unique habitat associations and are therefore referred to as generalists (Agosta 2002). Habitat preference is often associated with body size and wing shape, with clutter specialists having shorter wings and maneuverable flight, while aerial hawkers have long, slender wings and faster flight (Norberg and Raynor 1987). For example, species such as the northern long-eared bat (*Myotis septentrionalis)* and the small-footed bat (*Myotis leibii)* have short, broad wings, small bodies, and maneuverable flight, and are considered clutter specialists, foraging within the canopy (Taylor, 2006). Conversely, species such as the hoary bat (*Lasiurus cinereus*), which are large bodied and have long, slender wings, have higher wing loading (ratio of body mass to wing surface area) and require fast flight speed to stay aloft. Species with wing and body shapes like *L. cinereus* usually forage above the canopy, along forest edges, and within forest gaps as these habitats allow for fast, less maneuverable flight (Taylor, 2006). Species such as the gray bat (*Myotis grisescens)* and the tri-colored bat (*Perimyotis subflavus*) are considered riparian specialists, preferring to forage over riparian areas, close to their roosting site (LaVal et al. 1977), with the gray bat preferring forested riparian areas (Farlow et al. 2011). Both these species have flight speeds, wing shapes, and wing loadings associated with cluttered foraging habitats (Norberg and Rayner 1987).

There are 15 species of bats documented in Tennessee but only nine of those species have been documented in the study area (TSWAP 2015) (Table 1). There are no known published studies on foraging behavior and species composition of bats in higher elevations in the central Appalachian region. A study in central Greece that compared sites in shrublands (500, 1,000 and

1,500 m a.s.l), showed that species richness and the number of bat passes were not significantly affected by elevation (Georgiakakis et al. 2010). Another study in southern British Columbia, Canada suggested bat activity is significantly greater in riparian areas that are in lower elevations than riparian areas higher in elevation (Grindal et al.1999). Grindal et al. (1999) had capture rates that were biased towards females, especially in the riparian areas. Females were captured the most at lower elevations, whereas males were captured more often in higher elevation zones. This result could be because of differences in reproductive or thermoregulatory tactics between males and females or due to pregnant females being easier to catch in nets. Pregnant females could be more vulnerable to being captured as higher body mass would result in less maneuverability. Females may also require higher levels of nutrients that can be obtained in riparian areas (Grindal et al. 1999), suggesting that riparian habitats represent important foraging areas for bats. Erickson and Adams (2003), compared bat activity at low (< 150 m) and high (> 575 m) elevations in Black Hills, Washington, USA and found that *Myotis* activity decreased at high elevations while some other genera had similar patterns at both elevational gradients. Overall, this study found that bat activity was four times higher at low elevation sites (Erickson and Adams 2003). Different levels of activity among elevational sites could be driven by differences in prey abundance and weather conditions.

As there is currently no data available on elevational patterns of bat activity in the south central Appalachian region, the objective of this study is to compare levels of bat activity at low (< 914.4 m) and high (> 1, 524 m) elevations in open, forest edge, and riparian habitats in south central Appalachia. The hypothesis that there would be a significant effect of elevation on bat activity is tested to determine if, overall, lower elevation sites will have higher levels of bat activity. A second hypothesis, that certain species will be active in certain habitat types significantly more than other habitat types, is also tested to determine if species will be more active in habitats associated with their foraging habitats (e.g. open, edge, cluttered, riparian).

Table 1.1 Species and Their Preferred Habitat

Species	**Foraging Habitat Preferences**
Little Brown Bat (*Myotis lucifugus*)	Edge and Riparian
Gray Bat (*Myotis grisescens*)	Clutter and Riparian
Northern Long-eared Bat (*Myotis septentrionalis*)	Clutter and Riparian
Silver-haired Bat (*Lasionycteris noctivagans*)	Clutter and Riparian
Tri-colored Bat (*Perimyotis subflavus*)	Riparian
Big Brown Bat (*Eptesicus fuscus*)	Generalist, prefer open, edge, or riparian
Eastern Red Bat (*Lasiurus borealis*)	Generalist, prefer open, edge, or riparian
Hoary Bat (*Lasiurus cinereus*)	Open and Riparian
Evening Bat (*Nycticeius humeralis*)	Generalist, prefer open, edge, or riparian

Source: Schwartz, C.W. and E.R. Schwartz 2001

Methodology- Study Area

The lower elevation study sites (<914.4 m) were located at Hampton Cove Creek State Natural Management Area, located in Carter county, outside the town of Roan Mountain, TN, USA (Figure 1). It is managed by the Southern Appalachian Highland Conservancy (SAHC). The Cherokee National Forest and Pisgah National Forest contained higher elevation sites (>1,371.6 m). The Cherokee National Forest is within the Roan Mountain area of East Tennessee and the Pisgah National Forest is across the Tennessee state line in the area around Bakersville, North Carolina. In addition, this study utilized high elevation sites (>1,371.6 m) on property owned by the SAHC, in Roan Mountain, TN and Bakersville, NC (Figure 1.1). Roan Mountain consists of a series of peaks rising out of the landscape of the Appalachian Mountains. The habitat transverses from forests of hardwoods to spruce-fir, rhododendron gardens, and grassy ridge balds (Appendix A). Although some studies have been conducted on the property previously, there are no published studies that have examined how elevation affects foraging activity of the native bat species. Sampling at these higher elevation sites was conducted on Round Bald and Carver’s Gap, the spruce-fir zone above the highway and the bald, and along the Appalachian Trail. These high elevation sites include areas higher than those typically used in bat studies in the eastern United States.

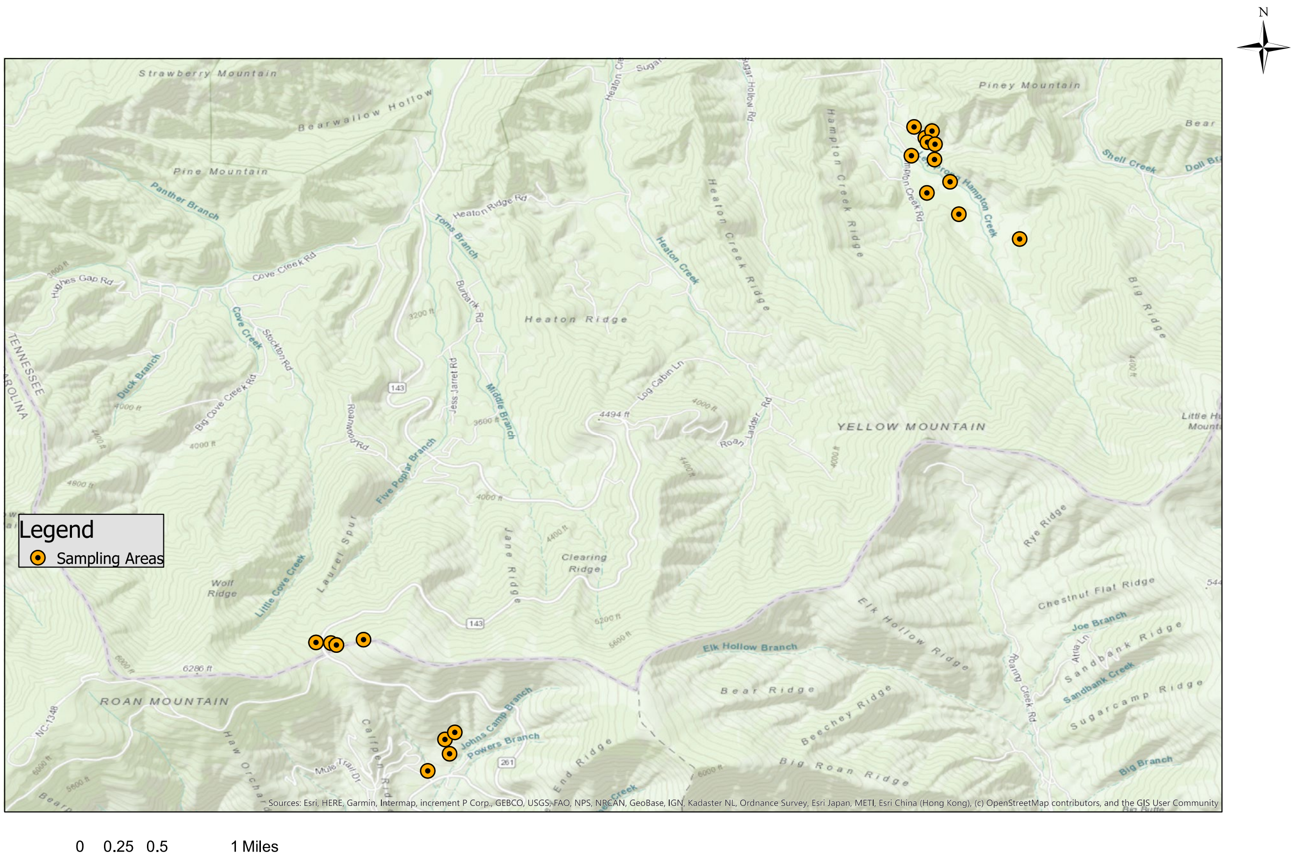

Figure 1.1 Map of study area

Acoustic Data Collection

Acoustic data provided the best opportunity for determining which species are present at the study sites and aided in identifying potential foraging locations for species of concern. Data was collected from Spring to Fall of 2019. To conduct the study, permits were acquired from the Cherokee National Forest Service, Pisgah National Forest Service, Tennessee Wildlife Resource Agency, and SAHC. Eight Song Meter SM4BAT FS (Wildlife Acoustics) detectors were deployed at a time and were placed at five low elevation sites and five high elevation sites for each habitat type: clutter, open, forest edge, and riparian. Detector settings were set accordingly. Minimum trigger frequency was changed to 20kHz, and schedule was set to sunset-30 to sunrise+30. Sample rate was set on 256kHz and maximum length was 15s. The trigger window was set to three seconds. All other detector settings were left on default. To randomize the experiment, the study area was displayed in ArcGIS with a numbered gridded zone overlay with 1km resolution and sites were selected with a random number generator. At sites close to forest edge, bat detectors were placed at least five meters away from edge habitat to avoid echoes. The Song meter SM4BAT FS detectors used in conjunction with the SMM-U2 ultrasonic microphones (Wildlife Acoustics, Maynard MA, USA) record high quality, full spectrum bat echolocation calls onto SD memory cards for later archiving and analysis on the laboratory computer. Recorded calls were analyzed with Sonobat 4, Southeast Suite, providing identification to species level. All bat species known to occur within the region were considered in the analysis and marked as either recorded or not recorded during each monitoring session; this will serve to eliminate problems relating numbers of echolocation passes to bat abundance. Call counts were used as a measure of bat activity. Data collected in the field were used to construct statistical models of the distribution of bats relative to habitat and landscape parameters (Jaberg and Guisan, 2001).

While acoustic recordings can be used to quantify how active a species is in a specific habitat type, they cannot be used to measure the number of individual bats that are active. Activity can be measured by counting the number of echolocation calls emitted by a species in a specific habitat. Species included in the analysis were big brown bats, hoary bats, silver-haired bats, red bats, evening bats, tri-colored bats, little brown bats, eastern small-footed bats, grey bats, Indiana bats, southeastern bats, and northern long-eared bats (Table 1). Species in the *Myotis* genus were grouped together due to the similarities in their echolocation call structure. Sonobat scrubber was set to medium scrub, which doesn't accept poor quality calls but does accept calls with some noise with tonal content (SonoBat). In order for an echolocation call to be assigned to a species, Sonobat had to provide ≥95% likelihood for acceptable call quality (Figure 1.2). The sequence decision threshold was set to 0.80 and the frequency of the call had to be in a range greater than 20kHz (Reichert et al., 2018). Calls that fell below this threshold were excluded from the dataset.

Figure 1.2 Picture of species ID from Sonobat. Laci is the abbreviation used for the hoary bat (*Lasiurus cinereus*). This species was identified by Sonobat with 99.03% confidence.

Results- ANOVA and Tukey-Kramer

Data collection started on May 27th, and sites were monitored biweekly until October 2nd. During the study period 10 weeks, 100 nights and 1,200 hours were sampled. During that time 98,107 sound files were recorded. After the files were scrubbed and vetted by SonoBat 81,576 files were used for the analysis. Table 1.2 shows bat activity for each week and the average of bat activity for low and high sites. The low sites had an average of 57,258 bat activity (μ=120.02, σ=392.32). While the upper sites had an average of 24,318 bat activity (μ=41.28, σ=100.33). Figure 1.3 displays the weekly differences in bat activity.

Table 1.2 Bat Activity for Each Week

Elevation	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Total	Nights/Hours
Lower (<914.4 m)	4678	3,632	7,727	8,526	2,407	7,240	7,432	8,819	1,711	5,086	57,258	100/1,200
Upper (> 1, 371.6 m)	2,366	1,771	1,591	3,699	4,082	1,338	1,119	2,113	3,256	2,983	24,318	100/1,200

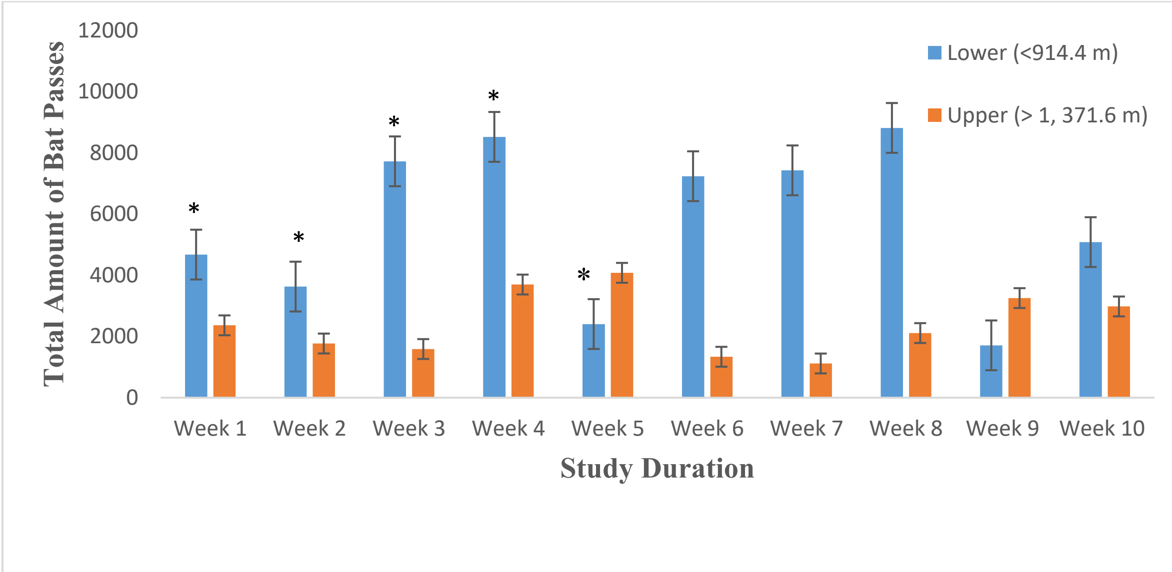

Figure 1.3 Bat activity for upper and lower elevation sites over the 10-week study duration. Error bars represent standard deviation. Asterisk marks (*) indicate significant difference (α=0.05)

Six species were grouped into the *Myotis* genus because echolocation calls for these species can often be misidentified. Weeks when the detectors went down, from either the battery dying, wind unplugging the microphone, or cattle unplugging the microphone were denoted with a period.

All statistics were run in SAS 9.4. The independent variables used for the ANOVA and Tukey-Kramer analysis were species ID and habitat type and the dependent variable was the number of echolocation calls. Data were considered normal following a Shapiro-Wilks test ($p>0.05$). Overall, bat activity was significantly different ($F= 44.22$, $p<0.001$, $\alpha=0.05$), at lower elevation sites than higher elevation sites (Figure 1.4).

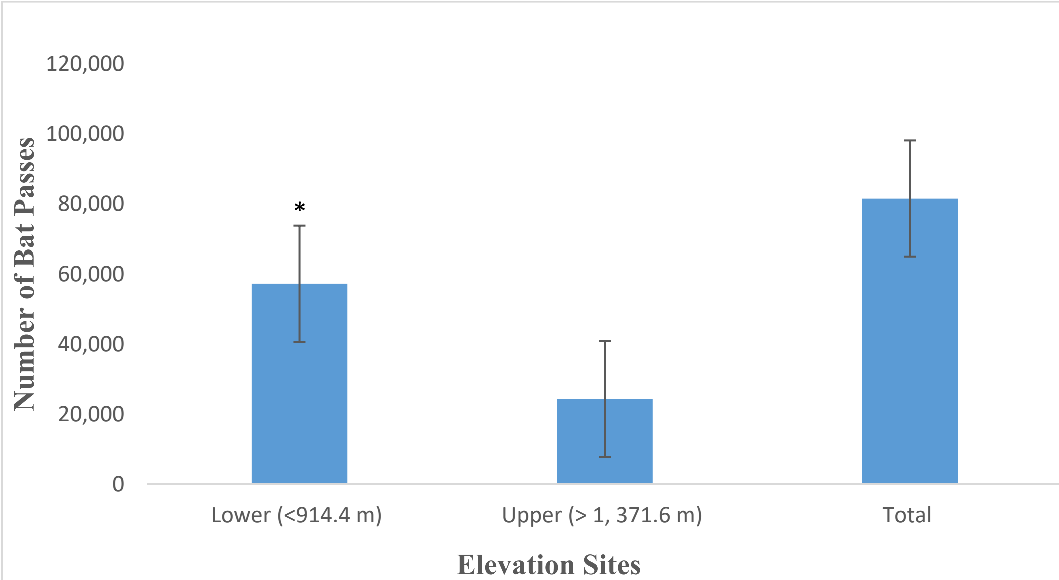

Figure 1.4 Comparing bat activity between lower and upper elevational sites. Error bars represent standard deviation. Asterisk marks (*) indicate significant difference (α=0.05)

A two-way ANOVA was used to test for interactions between the response variable, species activity, and the independent variables: elevation and habitat type. The interactions between species, elevation, and habitat were significant (F= 31.81, p<0.001, α=0.05). Since the interactions were significant, a Tukey-Kramer *post-hoc* test was used to determine which specific groups' means are different from each other. Big brown bat was found to be significantly more active (F= 49.89, p<0.001, α=0.05), at low elevations compared to all other species. This interaction was the only significant one identified by the Tukey-Kramer test for species and elevation. For the second *post-hoc* analysis, big brown and edge habitat were significantly different from all other interactions (F= 9.40, p<0.001, α=0.05). Big brown bats were found to significantly favor open habitats for foraging while no other species showed a marked preference for a particular habitat (p<0.001). An ANOVA was used to test for temporal interactions throughout the study. The study weeks were separated into early, mid, and late summer (Figure 1.5). The average for bat activity for early summer was 71.1 (μ=71.09 σ=287.45), mid-summer was 79.5 (μ=81.54, σ=269.15), and late summer was 69.67 (μ=76, σ=312.69). There was no significance found for bat activity between early, mid, and late summer (F=0.08091, p= 0.922284, α=0.05).

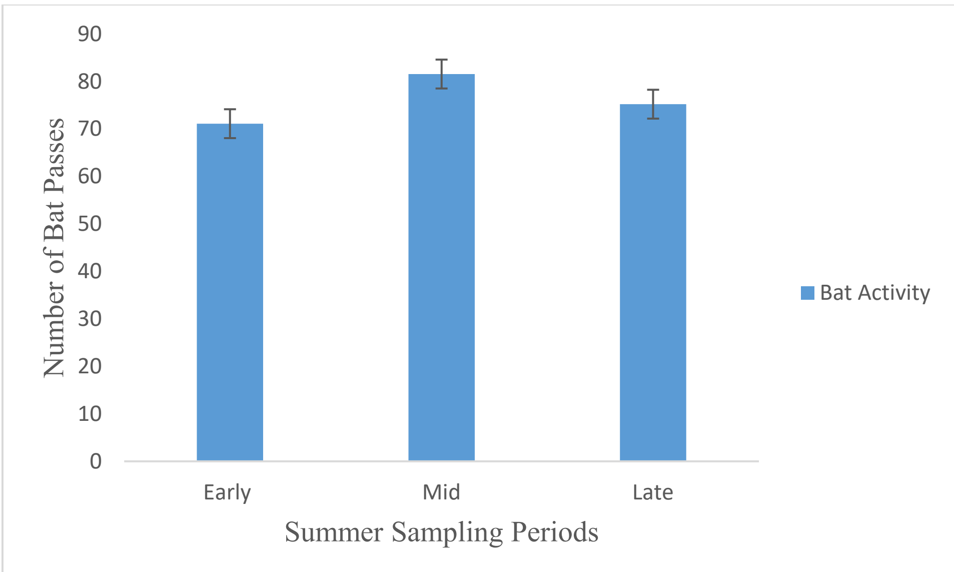

Figure 1.5 Comparing bat activity for summer sampling periods. Error bars represent standard error (α=0.05). There is no significant difference

Discussion

Species detected in the study were evening bats, big brown bats, hoary bats, silver-haired bats, tri-colored bats, and bats from the *Myotis* genus. Along with WNS, climate change is an additional risk bats, like many species are facing (Pecl et al. 2017; Frick et al. 2019). The earth is warming at an alarming rate, changing crucial habitat for much of earth's biodiversity (Pecl et al. 2017). Additional studies would provide more information of basic interactions between bats and their environments. Further research could provide information to government agencies on how bats make use of land that contains heterogeneous foraging habitat. Government agencies could then focus on restoring and preserving land for fauna and flora that are crucial for bats. The Tennessee Wildlife Resource Agency (TWRA) formed a state wildlife action plan for species of greatest conservation need in their 2015 (TSWAP 2015). In this plan they listed conservation concerns for bats, based on acoustic data. They were able to track WNS and colonies that were affected by this disease. They were able to buy property around two of the three largest caves in Tennessee. Protecting and acquiring habitat crucial to bats is one strategy the TWRA has implemented to protect bat species (TSWAP 2015). Discovering interactions between bats and habitat preferences is important to determine their effect on the environment. There have been similar studies conducted globally, but this project made specific connections on habitat and certain species in south central Appalachia (Bellows and Mitchell 2017; Caldwell et al. 2019; von Hirschheydt et al. 2020). The data generated here can be compared to other study areas in Appalachia, where research should be directed. The aim of this project was to provide basic ecology for bat species that is lacking in the eastern United States.

The first hypothesis was supported by the results. Bat activity was significantly higher in lower elevations than higher elevations. Lack of prey, water availability, and energy constraints could play a role in these results. Water is not as easily available in the higher elevations. In addition, vegetation is different in the higher study sites, resulting in different prey species and prey availability. Prey constraints may not be worth it for bats to utilize habitat in higher elevations. Energy constraints also play a role in habitat utilization. Bats use habitats best suited for their energy constraints, as indicated by their physiology. It may not be worth using up their energy resources to forage in higher elevations. Bat activity was not significantly different when divided into three temporal groups for the summer study period. Had the study covered more of the spring or fall, more variation could have been determined. The average summer temperatures did not vary much, thus, bat activity had no change. Support for the first hypothesis indicates that conservation efforts should be targeted towards lower elevation land in Southern Appalachia

Although this model showed some significant interactions, the second hypothesis was not supported. Bats have specialized feeding habitats, so data do not support what is shown in most of the literature (Norberg and Rayner 1987). Big brown bats showed a statistically significant preference for open foraging habitat which only partially supports the second hypothesis. The results concurrently showed that activity was significantly higher for big brown bats in open and edge habitats compared to all other species. But big brown bats had a total of 41,515 bat passes in low elevation habitats whereas all other species combined only had 8,016 total passes. This could also have influenced why big brown bats were more active in edge and open habitats at lower elevations. Big brown bats are the most common species in the study area, so significance from this species was expected. In addition, microphones in the forest may not have recorded as many clutter specialist species as microphones in open habitats. Bats using clutter habitats closer to the trees are harder to detect due to the tree foliage. Tree foliage can produce echoes and reduce the quality of the call detected. Furthermore, big brown bats use lower frequencies in their echolocation calls compared to some other species and lower frequency sounds travel further than higher frequency calls. Partial support of the second hypothesis does reveal the need for open foraging habitat in conservation efforts but roosting and hibernation habitat needs to be considered as well.

Bats species have been in decline since WNS was first introduced into the US. Many bat species are threatened or endangered due to this decline. Learning about bat behavior and how they utilize their environment is a great way to acquire data for management decisions. Data from this paper can play a crucial part in conservation. Federal, state, and non-profit agencies can use data like produced in this paper to make management decisions. Managers can buy and protect habitat for endangered species based on the type of habitat they utilize the most. The SAHC could use this data to protect open habitat because that type of habitat had the most bat activity. The agency could buy more land with open habitats to conserve for bat species. In addition, the agency could have more research conducted on all of their properties to have an overall picture of bat activity on their properties. Roosting is an important part of bats natural history, so protecting critical habitat is imperative for this species. Bats hibernate and require special habitat to roost in for hibernation and these often include wooded areas and cave systems. Managers could work towards protecting these areas based on how active bats are in the that area. Some bat species forage close to their roosting sites to avoid expending a lot of energy. Bats only have one pup each year, so protecting them is vital for the survival of the species. Overall, acquiring lower elevation land with a variety of vegetation profiles, from heavily wooded to open fields and cave systems, would provide foraging, roosting, and hibernation habitat for various bat species.

This study had a few limitations. Detectors were left out in seven-day time intervals. To add power to the project, more detectors should be used and relocated at least every two days for more replication. In addition, study areas should be monitored for at least two field seasons. One field season may not provide the best data for interpreting. For example, heavier than normal precipitation may reduce data quantity and quality. As bats do not forage in the rain, an unusually wet Spring and Summer would affect bat activity. The study area receives around 60.98 inches of rainfall on average per year (NACSE 2020). Summer temperature averages for the study area during 2019 were around 72.0 °F and spring temperature averages were around

65.6 °F (Northwest 2020). In addition, it would be beneficial to compare prey abundance for the study area. Low prey abundance in the study area could explain why there was no interaction between foraging activity and habitat. For future studies, a middle elevation should be sampled as well. A large area of the study site was missed in the mid elevational region, which could provide a further explanation of how species utilize the area. Overall, this project is a great start to a long-term project but should be continued to understand how bats use the landscape, different habitats, and how that varies by species.

CHAPTER 2. PREDICTED HABITAT CHANGE FOR BIG BROWN BATS IN THE US

Habitat suitability modeling is an instrumental tool that can be used in ecology and conservation biology to track global biodiversity. In addition, this type of modeling can be used to determine environmental effects on the distribution of important species. As bats are considered indicator species because of their large role in healthy ecosystems, understanding their species distribution at different levels is important. Along with WNS, climate change is also likely to negatively impact these important mammals. This study predicted habitat change for big brown bat species due to climate change in the United States. It evaluated various climatic variables and current habitat distribution for this species by 2050. Maxent was used to produce a model showing how habitat distribution will change for these species based on climate variables. Habitat modeling is a useful tool in many scientific studies. For ecologists and conservationists, modeling using presence data and climate data is especially beneficial. Exploring the potential risk of climate change on these species could be valuable since they are indicator species. Looking at indicator species could predict how climate change will affect other organisms in their ecosystem.

Studying bats can be difficult in many landscapes. Also, the nature of these nocturnal species can make fieldwork problematic. Bats are the second most speciose mammal group, yet they are still often misunderstood. To help fill these knowledge gaps, species distribution models (SDMs) can provide distributions at very fine spatial grains for many species (Herkt et al. 2016). One study used SDMs to predict distribution of nearly all 250 bat species in Africa at a resolution 1 km^2 (Herkt et al. 2016). Maxent modeling has been used to address the niche differences in the white-nose fungus (*Pseudogymnoascus destructans*) populations in different countries (Escobar 2014). They were able to identify potentially vulnerable areas for the disease to spread to in South America (Escobar 2014). In addition, they explored different environments and possibilities for why the fungus affected North American more than Europe (Escobar 2014).

One of the main threats to biodiversity is climate change (Costa et al. 2018). It has been linked to the decline of many species. Many studies use SDMs to predict the effects of climate change on bats. Costa et al. 2018 predicted potential impacts of climate change of bat diversity in Carajás National Forest (Eastern Amazon). They discovered out of the 83 species that were analyzed 47 of those species will not be able find suitable habitat by 2070 (Costa et al. 2018). Omnivorous bats may be affected the greatest by climate change, they could lose up to 36% of their suitable habitat (Costa et al. 2018). This will affect many plant species in the Amazon that rely on bats for pollination and seed dispersal (Costa et al. 2018). Another study used modeling to update distribution models for bats in Caatinga, Brazil (da Silva et al. 2018). They concluded that bat fauna in this area will be negatively affected because of deforestation and reduction of habitat (da Silva et al. 2018). With these findings in mind, they suggested in order to conserve bat species expansion of protected areas is needed (da Silva et al. 2018).

It is hypothesized that the distribution of big brown bats will be significantly altered by climate change by 2050. Based on ongoing changes in climate, the species may lose habitat in some areas, with possible increased habitat suitability in the western United States compared to decreased habitat suitability in the eastern United States.

Methodology- GIS and Modeling

Habitat sustainability for the big brown bat was modeled since it was the most prevalent species found in the study. Occurrence data or presence data for the big brown bat was downloaded from Global Biodiversity Information Facility (GBIF.org 2018). Data were spatially rarified using a tool in ArcGIS. This helped to eliminate points when there are multiple points in a 1 km block. Bioclimatic and elevation data for the model was downloaded from WorldClim.org (Hijmans et al. 2005). Variables used in the analysis were from the version 1.4 version. This was the version available when the model was produced. Variables chosen for this analysis were Bio 1 (annual mean temperature), Bio 2 (mean diurnal range), Bio 7 (temperature annual range), Bio 8 (mean temperature of wettest quarter), Bio 12 (annual precipitation), Bio 15 (precipitation seasonality), Bio 18 (precipitation of warmest quarter) and Altitude (elevation). These variables were chosen based on a collinearity tests that showed these were the most important bioclimatic variables for big brown bats. Representative concentration pathway (RCP) 2.6 were used in the model (Wayne 2014). There are four types of RCPs: RCP 8.5, RCP 6, RCP 4.5 and RCP 2.6 RCP (Wayne 2014). The RCP 2.6 was used because it is best case scenario indicating minimal rises in temperature and changes in precipitation. Best case scenario assumes that widespread policy changes are implemented and that populations do not rise quickly. RCP 4.5 and 6.0 represent moderate scenarios while 8.5 represents worst case scenario.

Maxent is a program for modelling species distributions from presence-only species records (Phillips et al. 2010). Many ecologist and statisticians use Maxent because it uses few variables and produces a high-quality model (Phillips et al. 2010). Maxent allows for simple interactions to be fitted using covariate features. Maxent's default settings provide a well-fitted model if occurrence data are accurate. Occurrence data for big brown bats in the United States and environmental variables were combined in Maxent to produce a model of habitat suitability. The model produced a best-case scenario for habitat change for big brown bats in the United States by 2050. Overall, Maxent is considered a reliable model to show bat habitat suitability (Reeder et al. 2012; Costa et al. 2018; da Silva et al. 2018).

After the model is created in Maxent, the output was analyzed to determine important environmental variables for each species. After the output is analyzed, the model can be displayed in AcrGIS. ArcGIS tools will be used to display unique values for the model and show four distinct areas in the region. For this model, the United States (contiguous) was analyzed. There were four distinct predictions displayed by the model: 0 contraction, 1 Absent, 3 Present, and 4 Expansion. Each region will be evaluated based on species habitat and climate patterns.

Results- Maxent Modeling

The model showed four different areas of habitat suitability for the big brown bat. This species will expand north and up into the Rocky Mountains (Figure 2.1). Big brown bats will not be found in parts of the southeastern United States. Additionally, this species will lose habitat in the southern United States.

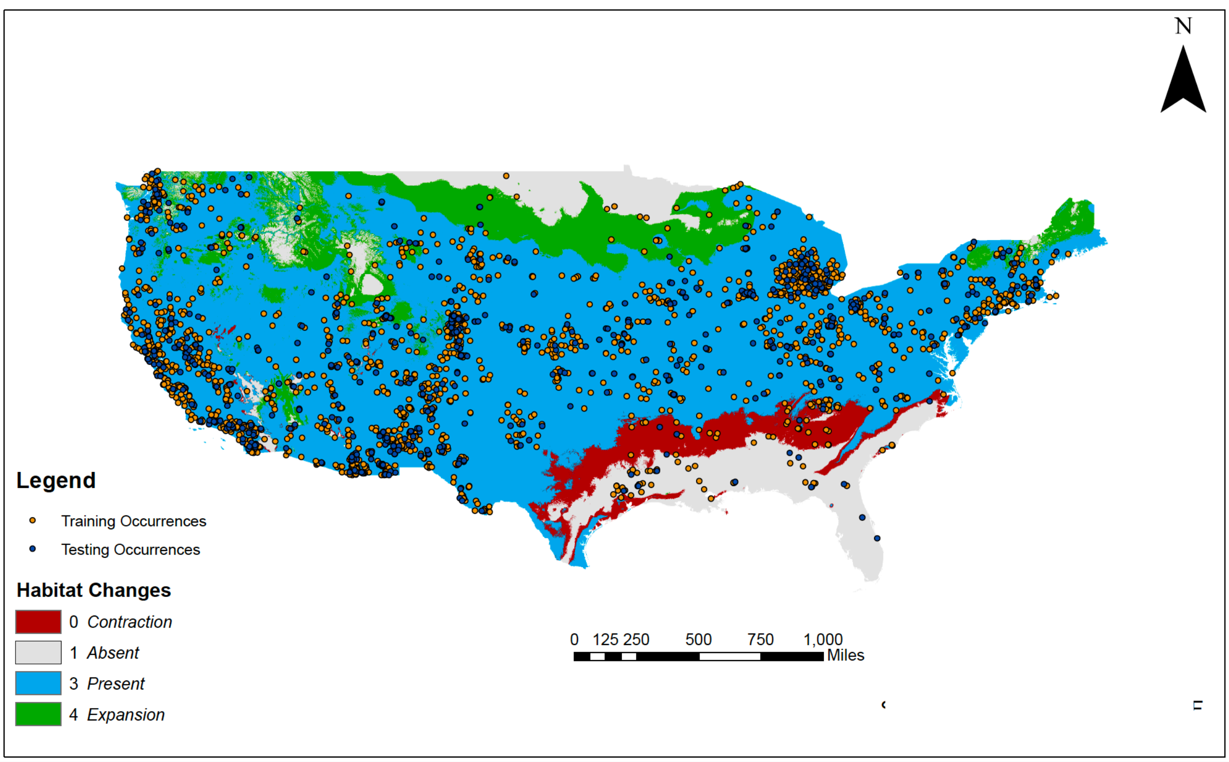

Figure 2.1 The map displays how habitat could change for the big brown bat by 2050. This was a best-case scenario. The green area on the map represented where the habitat would expand to, past their current distribution. The red area on the map represented habitat they species would lose if climatic variables do not change by 2050. The gray area on the map represents where species are not currently distributed. The blue area on the map shows where species distribution current and future projection overlap.

Looking at figure 2.1, you can see the limitations of the model. There are occurrence points for the southern US, however the model did not predict habitat in this area. Central Texas had several species points, but the model did not predict habitat in this area. There was also points in Florida, Georgia, Alabama, Mississippi and Louisiana, but the model did not predict anything in these areas. This is one of the limitations to using modeling for habitat suitability.

Maxent produces common thresholds and omission rates for the model. The threshold used for this model was the 10-percentile training presence. This threshold is commonly used throughout the literature, so it was used for this model as well (Phillips and Dudík 2008). This threshold value provides a narrow overview for species distribution and a better ecological result when compared with other thresholds values (Redon and Luque 2010). Therefore, the use of only one threshold value gives a very narrow overview of the species distribution. In addition, for conservation purpose it is more useful to have a presence gradient which is more realistic and easier to validate with expert knowledge. The commission predicted for this model was 65.4% and the omission rate was 8.7%. Figure 2.2 displays the receiver operating characteristic (ROC) curve for the data. The maximum achievable AUC is 1.0. Any AUC value above 0.5 indicates that the model performed better than random. The test AUC was 0.720, indicating an acceptable model.

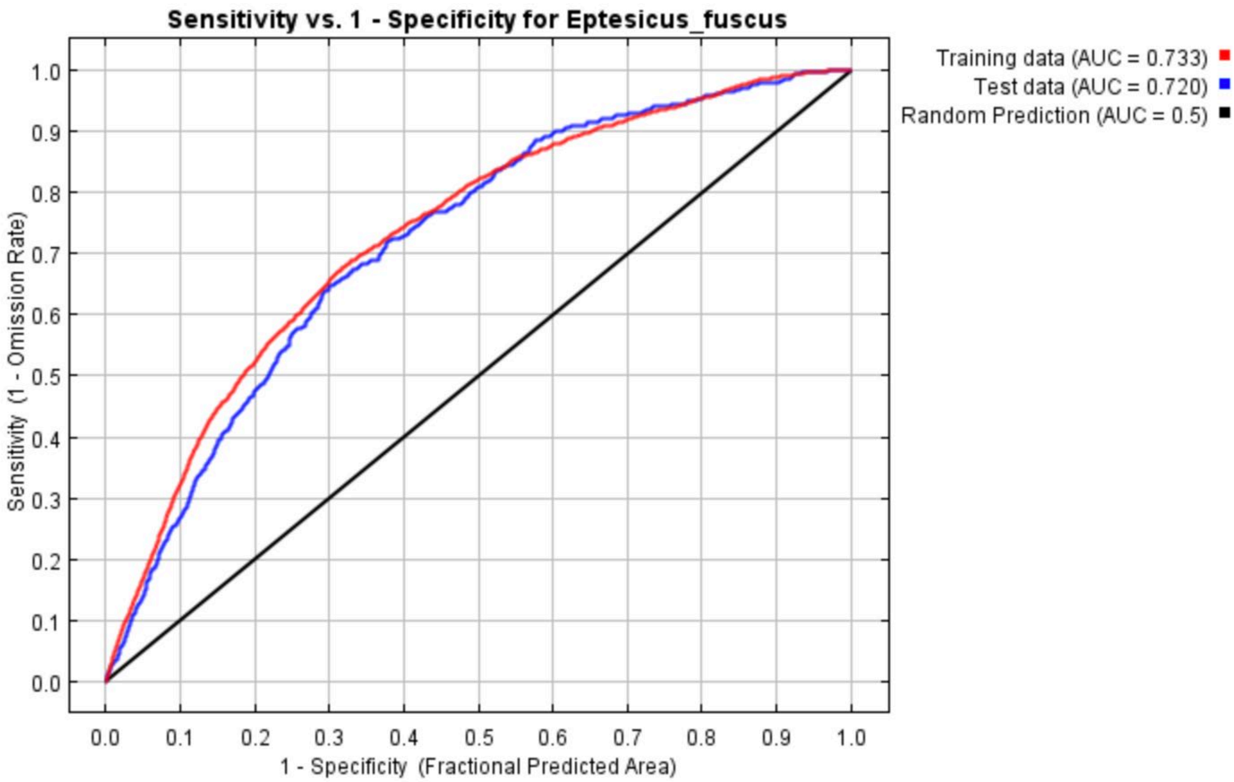

Figure 2.2 Omission rate and predicted area as a function of the cumulative threshold

The jackknife test (Figure 2.3), estimates contributions of each environmental variable. From this it can be concluded that Bio 1 (annual mean temperature) and Bio 15 (precipitation seasonality) contribute the most to this model. That means mean annual temperature and precipitation seasonality are the most important factors for the model. The environmental variable with the highest impact when used in isolation is Bio 1, which appears to have the most useful information. Bio 15 appears to have the second highest impact on the model. The response curve for Bio 1 showed that bats prefer a range of temperatures between 5 °C and 20 °C.

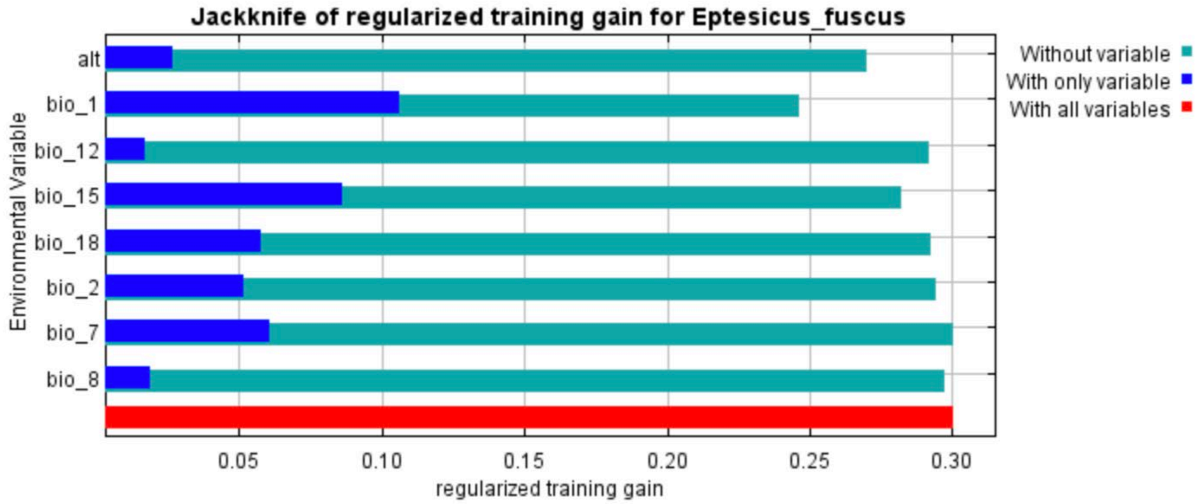

Figure 2.3 Jackknife test of variable importance

Discussion- Modeling

Habitat modeling is a useful tool in many ecological studies (Morisette et al. 2013). This paper suggestions SDMs can be used for evaluating different biological responses: life cycles, climate change, important habitat, response to habitat change, niche importance, invasive species etc. (Morisette et al. 2013). For ecologist and conservationist, modeling using presence data and climate data is especially beneficial. Bats are animals that play a large role in proper ecosystem function (Kunz et al. 2011). Exploring the potential risk of climate change on these species could be useful since they are indicator species. Examining indicator species could predict how climate change will affect other organisms in their ecosystem. For the purpose of this study, the big brown bat was used due to its abundance all over the United States. This species could be used as a comparison for other rarer species, since the effect on them would be greater. These bats are of special concern due to their susceptibility to changes in the environment. Climate change affects flora and fauna all over the world. The effects climate change has on bats has not been thoroughly studied for many species in North America. However, it is known that it affects reproductive success (Lučan et al. 2013). One study showed that increased temperatures could benefit juvenile bats in Bohemia, Czech Republic but if there was excess rainfall it would negatively affect reproductive success (Lučan et al. 2013). If the species are not able to reproduce successfully, the species will decline.

Additional studies would provide better information on the negative effects of climate change. Species that are endangered and threatened should be analyzed because they are at the greatest risk of extinction (Male and Bean 2005). Further research could provide actionable information to federal and state agencies who are in charge of land management policies. This information would allow agencies to make informed decisions for species conservation. There are limited studies looking at the effects of climate change for bat species across the United States. This is a growing problem that should be evaluated further.

The results of this model showed that climate change could possibly shift bat habitat to the northern United States. However, the shift in habitat is not significant. Big brown bats are habitat generalist, so this small change in habitat makes sense. This species can use a variety of habitats, so climate change may not have a big effect on the habitat they use. If the habitat for this species shifts, animals left in the ecosystems where bats are predicted to no longer exist could face a significant decline. In addition, climate change could possibly increase prey for bat species, which would be beneficial for bats. The model also revealed that the most important factor effecting big brown bats is temperature. It showed that bats prefer a range of temperatures between 5 °C and 20 °C. This also makes sense because an increase in temperature could affect water resources, driving the species father north for this resource. The model supports this conclusion by showing a habitat moving northward for this species.

Overall, modeling some limitations. This model didn't predict distribution in parts of southeastern U.S even thought there were occurrence points in the southern US. There were many points in central Texas, so the model should have displayed present data there. There are other problems when using presence-only data. There can be sample bias associated with using presence-only data (Phillips et al. 2010). Large datasets downloaded from organizations can often be a compilation of data. This means that many people sampled a species and provided information on it separately. Different groups of people sampling over large areas can cause geographical bias. Some areas in the model may not have been efficiently while others were. Some may see think this type of data is bias; However, Maxent modeling serves to minimizes this when possible (Phillips et al. 2010). To improve these limitations further, a bias file could have been used to reduce model bias caused by over-sampling in some areas. In addition, parameters chosen for Maxent could have been changed from the default setting to deal with pseudo-absences and overfitting or overpredicting issues. Ultimately, the limitations with this model could have been resolved by changing parameters within Maxent.

To improve this study, parameters within Maxent should be changed to reduce overfitting and overpredicting issues. In addition, creating and adding a bias file to the model would improve the accuracy of this model, and help avoid over-sampling in some areas in the study. To further this study, more species should be analyzed, and different variables should be considered. To improve this study, individual species should be chosen and analyzed in relation to prey rather than climate variables. This way there is less variance between species. Overall, this project represents the beginning of a long-term project and should be continued to understand how bat habitat will change with varying weather patterns.

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APPENDICES

Appendix A: Pictures of the Study Area

Grassy Bald (Open Habitat)

Edge Habitat

Clutter Habitat

Riparian Habitat

Rhododendron Garden

Christmas tree farm

Appendix B: SAS Code for ANOVA and Tukey-Kramer

```
proc sort data=bat;
by elevation habitat species;
run;

proc univariate data=bat normal;
qqplot abd /normal;
run;

proc glimmix data=bat;
class week elevation habitat species;
model abd=elevation / dist=lognormal;
random week habitat species;
run;

proc ANOVA data=bat;
class week elevation habitat species;
model abd=elevation abd=habiat abd=species;
means elevation habitat species / hovtest welch;
run;

proc glm data=bat plots=diagnostics;
class week elevation habitat species;
model abd=elevation;
output out=residfit p=yhat r=resid;
run;

proc means data=bat mean stderr;
```

```
var abd;
by elevation habitat species;
run;

proc glm data=bat plots=diagnostics;
class week elevation habitat species;
model abd = elevation species habitat elevation*species species*habitat;

output out=residfit p=yhat r=resid;
run;

proc glm data=bat;
class week elevation habitat species;
model abd = elevation species habitat elevation*species species*habitat;
lsmeans elevation*species species*habitat / pdiff adjust=tukey;
run;
```

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