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East Tennessee Spatial and Temporal Species-Specific Bat Activity Patterns

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East Tennessee Spatial and Temporal Species-Specific Bat Activity Patterns

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ABSTRACT

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Determining the activity among species-specific bat populations within specific habitat selections can help contribute to the conservation of Appalachian bat species. This study examines the differences in species-specific bat activity patterns between three ponds of variable sizes and a southeast-facing open field with a wooded edge. Four Song Meter SM4BAT FS bioacoustics detectors were used on a 15-acre property in Fall Branch, TN, with a wildlife acoustics detector being placed at three ponds and one field. There were three stages of data collection for this study which all took place during 2023. The first stage was during the spring (March 18th – May 18th), the second stage was during the summer (June 21st – August 27th), and the third stage was during the fall (September 26th – October 26th). Acoustic recordings were analyzed through SonoBat to classify them to species level using a recording call quality threshold of ≥ 95%. An identification likelihood of ≥ 90% yielded 36,308 calls assigned to a particular species/genus. The acoustic detectors detected eight bat species and the Myotis genus throughout the study. Species identified include Rafinesque's big-eared bat (*Corynorhinus rafinesquii*), big brown bat (*Eptesicus fuscus*), hoary bat (*Lasiurus cinereus*), silver-haired bat (*Lasionycteris noctivagans*), eastern red bat (*Lasiurus borealis*), evening bat (*Nycticeius humeralis*), tricolored bat (*Pipistrellus subflavus*), Mexican free-tailed bat (*Tadarida brasiliensis*), and species within the *Myotis* genus. Two chi-square analyses were performed through R to determine if there were significant spatial and temporal species-specific activity

patterns between the four sites. Both chi-square analyses resulted in a p-value < 2.2e-16 indicating significant differences in species-specific activity levels between the four sites throughout spring, summer, and fall. This data can help species-specific conservation efforts by understanding bat species' activity levels at particular habitat selections throughout the fall, summer, and spring seasons.

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Ecological and Economic Importance

Bat conservation is essential due to their ecological and economic services (Ducummon 2000). Bats help contribute to healthy ecosystems by providing services that improve human well-being through regulatory processes, supporting processes, and cultural benefits (Kunz et al. 2011). Ecological and economic benefits from bats can be interconnected through insect population control, dispersal of seeds and pollen, and soil fertility through guano excrement.

Ecologically and economically speaking, frugivorous and palynivore bats contribute to pollination and seed dispersal. An example of the importance of bat pollination can be seen through agave plants which are used are used to produce tequila, and without the presence of bats, the propagation of agave has been determined to decrease (Ducummon 2000). Frugivorous bats contribute to seed dispersal, helping ecosystem succession in tropical and neotropical environments by covering long distances at night and dispersing seeds through excrement. Bats are known to contribute economically through seed dispersal for trees that have agricultural purposes and are used in the timber industry. However, it is challenging to examine, and the proportion of plant seeds dispersed by bats is less significant than that of birds (Kasso and Balakrishnan 2013). The economic services bat pollinators contribute to agriculture are also difficult to examine, but a study showed that 289 Old World tropical plant species depend on bat pollinators. These plant species produce 448 products, such as timber, food, wood products, and medicine, that depend on bat pollination (Fujita and Tuttle 1991). The tropical almond tree is an example that has been recorded to be dispersed by bats and is used for shade, fuel, food resources, and tannin extraction (Kasso and Balakrishnan 2013). Despite the understanding that bats are essential natural resources and provide excellent ecosystem services, it is challenging to determine the ecological values bats hold on their ecosystems (Kasso and Balakrishnan 2013).

The economic and ecological importance of insectivorous bats can be seen through bats being a natural pest control, preying on insects that significantly affect agriculture and forests. Boyles et al. (2011) suggested a substantial loss of bat populations could lead to yearly agricultural losses of roughly $3.7 billion. It has been determined that a colony of one million Brazilian free-tailed bats weighing 12g each could consume up to 8.4 metric tons of insects in one night (Kasso and Balakrishnan 2013). A colony that holds around 150 big brown bats (*Eptesicus fuscus*) has been estimated to disrupt the population cycles of agricultural pests by consuming 1.3 million pest insects each year (Boyles et al. 2011). Evaluating the economic significance of bats as pest control is also challenging due to the need for more understanding of foraging behavior and dietary constraints for many species of bats (Kasso and Balakrishnan 2013).

Bats also have been determined to help ecologically with soil fertility and nutrient distribution through their ability to travel long distances from their roost to foraging habitats while producing guano droppings during travel (Kasso and Balakrishnan 2013). Guano is also a significant economic service produced by bats due to the economic value it holds by supplying the finest natural fertilizers (Sakoui et al. 2020). In summary, the economic and ecological services bats contribute to are indispensable to the well-being of humanity and are, therefore, a significant influence on conservation efforts.

Threats on Bats

Bats are the second largest mammalian order consisting of around 1300 extant species, and are located on every continent except Antarctica (Kunz and Parsons 2009; Voigt and

Kingston 2016). Major threats on bat populations globally have caused concern and increased interest in pursuing conservation efforts properly, with anthropogenic activities impacting global bat populations the most. The IUCN (International Union for Conservation of Nature) assessments determined that land use change, urbanization, hunting and persecution, and quarrying are significantly impacting bat populations (Voigt and Kingston 2016).

As forests and caves are essential habitats for bats because they support local abundance, species composition, species diversity, and foraging habitats (Frick et al. 2020), the need for conservation is vital. For example, the continued degradation of tropical rainforests through clear-cutting in Southeast Asia threatens global bat diversity due to vast areas being exposed to edge effects (Broadbent et al. 2008; Frick et al. 2020). Therefore, there is a push to regulate management practices in regions logged by establishing “spatial-temporal heterogeneity” in forest structure and landscape by retaining mature trees. This effort is expected to mitigate some of the negative consequences of timber harvest (Frick et al. 2020). Though, assessing the impacts of anthropogenic land management practices on forest-dwelling bats is difficult due to their dispersed roosting habits. (Frick et al. 2020).

Agriculture is another land-use strategy that has dramatic effects on bat populations and is happening on a global scale. The IUCN estimated that agriculture globally impacts 50% of threatened bat species (Frick et al. 2020). The clearing of forests to grow crops not only removes foraging and roosting habitats but also introduces monoculture as a replacement. Monocultural practices affect biodiversity on a large scale by only attracting specific species capable of sustaining themselves in a particular crop (Voigt and Kingston 2016). Additionally, using insecticides on crops has also been determined to reduce insect abundance, further impacting foraging capability, and can also poison bats (Voigt and Kingston 2016).

Urbanization is yet another anthropogenic effect on global bat populations and corresponds with the growing human population. While there is still much to learn about how urbanization affects bat populations, it is known to decrease bat activity and species richness (Voigt and Kingston 2016). This loss of species diversity in urban settings is likely due to the loss of grasslands and tree cover, which are important habitats for the foraging and roosting of bats. With the increase of urbanization, there is also an increase in ecological light pollution through artificial lights. This is known to affect the natural rhythms of light and dark in ecosystems (Longcore and Rich 2004). The effects caused by ecological light pollution can be seen in bats and other vertebrates and invertebrates by negatively influencing circadian and circannual cycles (Voigt and Kingston 2016).

Being the second largest mammalian order and occurring in diverse habitat ranges globally, Chiroptera is an exceptional order in studying the effects of climate change on vertebrates (Festa et al. 2022). Climate change has been determined to have substantial impacts on global biodiversity. Major threats corresponding with climate change are temperature rises, precipitation patterns shifts, and increased occurrence of natural disasters (Festa et al. 2022). The consequences of climate change can also be species-specific among Chiroptera. For instance, with the fluctuation of temperature and changes in precipitation, insect flight may decrease in areas that receive more rainfall, and seasonal flowering and fruiting plants may be affected by the temperature fluctuation. This impedes insectivores bat species that rely on hunting insects by flight and frugivorous bats that depend on the annual fruiting from plant species. However, some species with flexible hunting strategies, such as the Daubenton's bats *Myotis daubentoniid,* may not be affected dramatically by temperature and precipitation changes (Sherwin et al. 2012).

Infectious diseases throughout the animal kingdom also pose major threats and cause negative dynamics for the infected species. Species extinction comes into play if a disease is introduced, and the transmission of the disease does not decrease, causing a population decline. (Frick et al. 2015). *Pseudogymnoascus destructans,* commonly known as white-nose syndrome (WNS), is a fungal disease that has been devastating bat populations in North America since it was first detected from an irregular mortality rate at a cave in Albany County, New York, USA, in 2007 (Hoyt et al. 2021). Since WNS was detected in 2006, it has been recorded in thirty-nine US states and seven Canadian provinces (Hoyt et al. 2021). This fungal disease has established a conservation concern in bat populations that hibernate in vast colonies due to its fast transmission rate during the winter. There is a variation in the decline of bat species caused by WNS, but millions of bat mortalities have been recorded to be caused by WNS (Hoyt et al. 2021). Little brown bats (*Myotis lucifugus*) have experienced significant population declines throughout the United States, with 96% in the Northeastern US, and 97% in the Midwestern US, and declines in the Southern US have been noticed but need further assessment. By contrast, populations of big brown bats (*Eptesicus fuscus*) have stabilized since the arrival of WNS in the US, but are not increasing back to pre-WNS levels. (Hoyt et al. 2021).

Ecology of Bats

Located globally, Chiroptera is a diverse order inhabiting temperate, topical, and subtropical regions. Species within the order Chiroptera have adapted many differences in roosting, foraging, and migration behaviors associated with the geographical region the bat species utilize. The behavior differences depend on the food supply, temperature, reproduction, and roosting selection. These ecological niches are all interlinked and are valuable for understanding the life histories of species that are threatened by anthropogenic caused effects.

Understanding bat species' foraging, roosting, and migration behavior is crucial for effective conservation planning, especially for endangered bat species (Fenton 1997).

Migration within the order Chiroptera is an ecological behavior that has been studied to gain an understanding of the life cycles of bat species that endeavor this event. Migration is typically a two-way movement from one geographical region to another in search of advantageous climate conditions (Fleming 2019). Bat species that inhabit seasonal temperate and tropical regions undergo migration for ecological reasons dependent on the region. For example, bats in seasonal temperate regions will migrate to avoid cooling air temperatures, less food availability, locating stable torpor conditions, and reproduction. Temperate bat species undergo three categories of spatial behavior, and bat migration patterns differ between and within species (Fleming et al. 2003). The categories include sedentary (nonmigratory) bats that stay within 50 km of the preferred habitat, regional migratory species that migrate 100-500 km from summer to winter habitats, and long-distance bat species that migrate 1000km or greater during seasonal shifts (Fleming 2019). Migration in tropical bat species is less common because avoiding cooler winter temperatures and hibernation is typically unnecessary. Tropical bat species that do migrate follow the annual flowering and fruiting cycles of plants for a food resource. (Fleming 2019). Migration is an expensive ecological behavior, and the reward must outweigh the risks and cost for a bat to undergo such a process.

Roosting behavior is also a vital part of a bat’s life cycle as it provides sites for hibernation, mating, rearing of young, protection from predators, and avoiding harmful weather conditions (Kunz et al. 2003). Bats roost in various structures, including natural structures such as caves, cavities constructed by other animals, tree branches and trunks, foliage, exfoliating bark, and tree cavities (Kunz et al. 2003). Artificially structured roosts include mines, tombs, buildings, and bridges (Kunz et al. 2003). Tree cavities are widely used for roost sites by bats, especially in temperate and tropical regions. Certain bat species are attracted to particular trees for roosting purposes, especially bats that roost in cavities. Larger trees and the amount of bark present are influential in selecting a roost site by cavity roosting bat species because more heat is retained with better insulation (Kunz et al. 2003; Nicolai 1986). Understanding species-specific roost selection can help further conservation practices, particularly when performing logging, clearcutting, and prescribed burns.

The foraging behavior of bats is complex and species-specific due to their diet, morphology and physiology, and the region the species inhabit. Within Chiroptera, there are insectivorous, frugivorous, palynivores, and nectarivorous species, all well adapted to their dietary behavior. Insectivorous bats have varied feeding habits, with some species being specialized among prey available within their habitat and others being generalist predators (Kasso and Balakrishnan 2013). Determining insectivorous bats' prey selection can be difficult due to the large scale of insects these bat species target (Fenton 1982). Bat species dependent on plants for food resources, such as nectar, pollen, or fruit, are mostly restricted to tropical regions (Fleming 1982).

Focus of the Study

This study focuses on determining spatial and temporal species-specific bat activity by comparing echolocation call quantity between three ponds and one field throughout the spring, summer, and fall seasons. I hypothesize that there will be a significant difference in activity between the species detected at the three ponds and one field and throughout the spring, summer, and fall seasons. I predict that there will be a significant difference in species-specific bat activity between the three ponds compared to the open fields because of potential differences in prey selection and abundance, and low clutter. I also predict that there will be a difference in species-specific bat activity between the three individual ponds because of the differences in sizes, and the amount of vegetation clutter surrounding the ponds attracting certain bat species that can utilize cluttered habitats. Lastly, I hypothesize that there will be a significant difference in the distribution of species-specific bat activity throughout the spring, summer, and fall seasons due to food abundance, species competition for space, migration, and species-specific habitat selection.

Chapter 2. Methods

Study Site

The study site is on a 0.239 Km^2 private property in Fall Branch, Tennessee. The property was once used for agricultural purposes, particularly cattle, but has not been used for agriculture since 2018. The property is not mowed or managed, so the vegetation is free to overgrow. Three ponds of various sizes and a southeast-facing open field are located on the property and were used for this study. There were four Song Meter SM4BAT FS bioacoustics detectors (Wildlife Acoustics) used, with one placed at each site (three ponds and one field) and labeled accordingly (Figure 1).

Figure 1: Map of study sites with detector placement and labels (Photo: Google Earth)

Big pond is 1,537.805 m^2 and has an average depth of 0.701 m (Figure 2). It is located on the west side of the property, surrounded by thick vegetation consisting of oak trees, maple trees, tulip trees, cedar trees, and various understory plants. Medium pond is 1,092.65 m^2 and has an average depth of 0.396 m (Figure 4). It is located on the southeast end of the property, surrounded by cedar trees. Small pond is 607.028 m^2 with an average depth of 0.274 m and is also located on the southeast end of the property, surrounded by cedar trees (Figure 5). The field is 0.0379 km^2 consisting of post-agricultural growth of fescue and cool-season grasses (Figure 3). It has a southeast-facing slope with a wooded edge comprised primarily of oak, maple, tulips, and a moderately thick understory.

Figure 2: View of Big Pond

Figure 3: View of Southeast-facing Open Field

Figure 4: View of Medium Pond

Figure 5: View of Small Pond

Acoustic Data Review

Bioacoustics data sampling is useful when determining what bat species are active in various habitats during a particular season. Three stages of the study were performed during the spring, summer, and fall seasons in 2022. Bioacoustics detectors were placed at each site (three ponds and one field) from March 18th – May 18th, during the first stage in the spring. During the second stage, the bioacoustics detectors were redeployed in the field from June 21st – August 27th during the summer. The third stage started from September 26th – October 26th during the fall. Due to harsh weather conditions, wildlife, and batteries life issues, the bioacoustics detectors did not record every night of their deployment.

The four Song meter SM4BAT FS detectors used for the study consisted of an SMM-US ultrasonic microphone that recorded full spectrum echolocation calls. All four detectors were deployed with the same settings. For the audio settings, the gain was set to 12db, and the 16k high filter was set on. The sample rate was set at 256kHz. The minimum duration was set to 3.0ms, and the maximum duration was left at none. The minimum trigger frequency was moved up to 17kHz, and the trigger level was left at 12db. The trigger window was set to 3.0s with a maximum length of 15s with no compression. For the location settings, all the detectors were set with the same coordinates due to their close proximity with latitude set at 36.42010 N and longitude 82.60715 W. Sunrise/ sunset type was set to solar, and the schedule was set to start 30 minutes before sunset and end 30 minutes after sunrise (Sonobat).

The echolocation calls recorded were saved to an SD memory card in the field and archived on the laboratory workstation. Call analysis was done in Sonobat 4 using the Southeast suit and Western Kentucky region species list. Sonobat provides call identification to species, and data can be used to determine the species present and the activity at the particular field site. As one bat can emit many calls in any specific field site, these data do not measure the number of individual bats for a population count. Sonobat was set to provide ≥95% of acceptable call quality (calls that fell below this quality threshold were removed from the analysis), and the sequence decision threshold was set to 0.80. Sonobat would then give a probability of what species the call belongs to, and the calls that were accepted and used for this study had to be an identification likelihood of ≥90% (calls that fell below this quality threshold were removed from the analysis). Two chi-square analyses were performed in R to analyze spatial and temporal species-specific bat activity with an alpha of 0.05 (Sonobat).

Chapter 3. Results

Bat Activity Comparison

A total of 47,091 calls were recorded and analyzed with Sonobat. From that, only 36,308 calls were of acceptable quality and achieved an identification likelihood of ≥90%. Species-specific bat activity was compared across field sites and across season.

Eight bat species and the *Myotis* genus were detected throughout the study. The species within the Myotis genus was grouped due to their highly similar echolocation call frequencies. Species identified included Rafinesque's big-eared bat (*Corynorhinus rafinesquii*), big brown bat (*Eptesicus fuscus*), hoary bat (*Lasiurus cinereus*), silver-haired bat (*Lasionycteris noctivagans*), eastern red bat (*Lasiurus borealis*), evening bat (*Nycticeius humeralis*), tricolored bat (*Pipistrellus subflavus*), Mexican free-tailed bat (*Tadarida brasiliensis*), and species within the *Myotis* genus. Species abbreviations are as follows: Rafinesque's big-eared bat (Cora), big brown bat (Epfu), hoary bat (Laci), silver-haired bat (Lano), eastern red bat (Labo), evening bat (Nyhu), tricolored bat (Pesu), Mexican free-tailed bat (Tabr), Luso is a combination of little brown bat and Indiana bat, and then the *Myotis* genus.

The chi-square analysis comparing site vs. species resulted in an X-squared value of 7,891.3 (d.f. 27, $p < 2.2e-16$), indicating that there is a significant difference in species-specific bat activity between all four sites (Fig 6). The chi-square analysis comparing season vs. species resulted in an X-squared value of 5,554.3 (d.f. 18, $p < 2.2e-16$), indicating that there is a significant difference in species-specific bat activity between the spring, summer, and fall seasons (Fig 7).

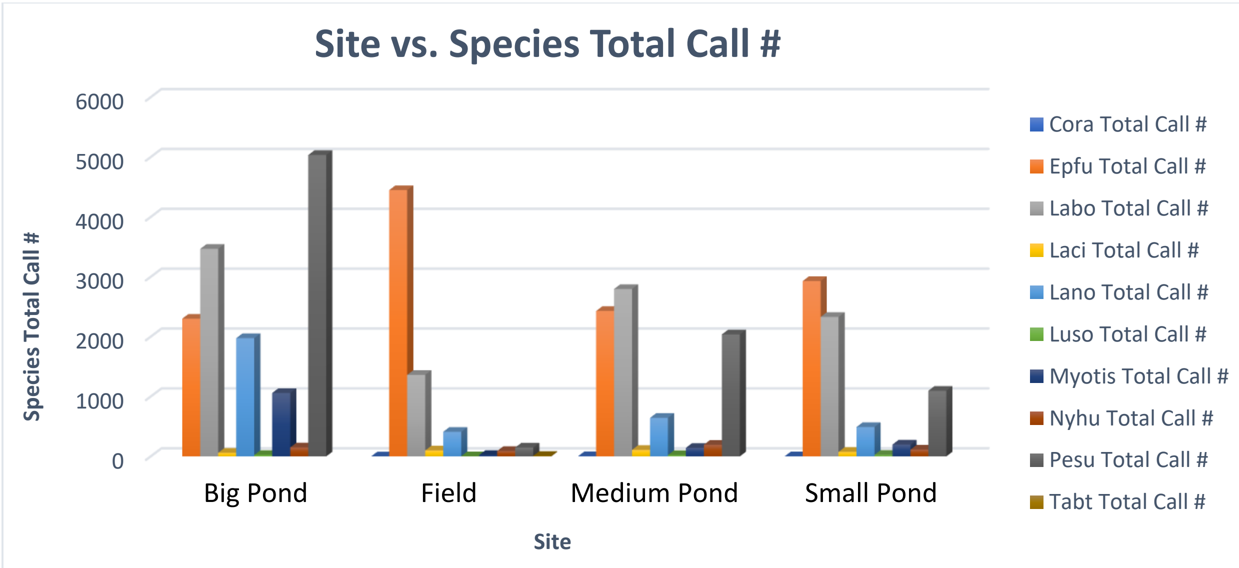

Figure 6: Site vs. Species Total Call # Bar Chart

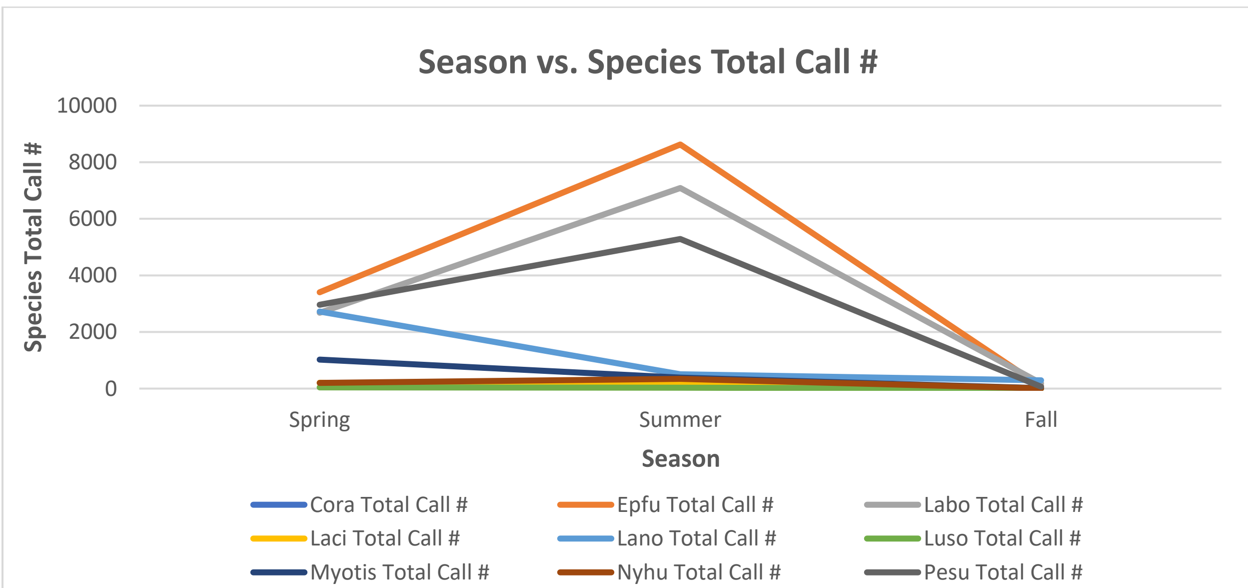

Figure 7: Season vs. Species Total Call # Line Chart

Chapter 4. Discussion

This study aimed to examine spatial and temporal species-specific bat activity levels across three ponds of various depths and sizes throughout the spring, summer, and fall seasons. Species-specific bat activity was compared at these sites as well as throughout the seasons by bioacoustics recordings. I hypothesized that there would be differences in species-specific bat activity across the sites and throughout the spring, summer, and fall seasons. The analysis supported the hypothesis of differences in species-specific bat activity levels between the three ponds and one field, along with differences in activity across the spring, summer, and fall seasons. This can be explained through species-specific foraging behavior targeting specific insect species present in the ponds compared to the open field and vis versa. Insect species abundance between the three ponds can also be a factor in the differences in species-specific bat activity between the three ponds. Bat activity in the field could be explained by bat species using the field as a corridor going from roosting to foraging habitats. Overall, this study determined a significant difference in species-specific bat activity between various-sized ponds and open field land and a significant difference in activity levels among bat species throughout the spring, summer, and fall seasons. These results contribute to understanding species-specific habitat selection and how certain species utilize their resources, which helps further efficient conservation planning for East Tennessee bat populations.

Passive Acoustic Monitoring

Passive acoustic detectors have expanded ecological research by making research more affordable, maintainable, and deployable, allowing for large-scale datasets. Passive acoustic sampling can be used to determine community structure, species-specific echolocation call characteristics, species activity levels, species richness, and species composition of bats in various habitats (Brooks and Ford 2005; Froidevaux et al. 2014). The efficiency of acquiring data from passive acoustic monitoring establishes a better understanding of species-specific life histories and a deeper insight into how bats utilize specific habitat structures. However, passive acoustic monitoring is unreliable in accounting for numbers of individuals within a population and therefore does not give accurate population estimates.

Spatial and Temporal Bat Activity

Studies have been performed to assess bat community structures, species composition, species richness, and species-specific bat activity levels over bodies of water to examine how bats utilize such habitats. The ability to acquire a stable water resource is essential for bats due to their high body surface-to-volume ratio, which causes high exposure to dehydration (Ancillotto et al. 2019). Ponds are great for studying species-specific activity levels because of the variation between habitat location, size, depth, surrounding vegetation, insect abundance, and if it is naturally occurring or human-made.

Morphological characteristics have been determined to be an important factor in species-specific bat activity around ponds depending on the amount of vegetation clutter surrounding the pond. Larger-bodied bat species with high wing-loading are faster flying and less maneuverable such as *Eptesicus fuscus* (big brown bat), are known to prefer open habitats, and avoid thick vegetation. Smaller-bodied bat species with low wing-loading, such as *Myotis sodalist* (Indiana bat), can maneuver in cluttered vegetation (Brooks and Ford 2005). The differences in morphological characteristics can explain the results of this study. For instance, the big brown bats were recorded more frequently at the small pond (fig 6), possibly due to less vegetation clutter surrounding the pond. While at the big pond, tricolored bats have the most recordings compared to the other species. This could be explained by the fact that Tricolored bats have low wing loading and can maneuver in the thick vegetation surrounding the big pond. Competition for space and foraging habitat between species may also explain the higher number of big brown bats are present at certain sites with a decrease in the number of recordings of the other species. Big brown bat activity was much higher than other species across the sites, which can be explained due to their generalist foraging behavior. Understanding the forces driving species-specific bat activity levels around a valuable water source like a pond can help further management of conservation for endangered species such as *Myotis lucifugus* (little brown bat).

There is little research regarding how bats species utilize open fields specifically. However, there is research focusing on bat open-space foraging utilizing linear landscapes such as tree lines. Tree lines can be created by clear-cutting for agricultural purposes or seen naturally in rocky environments where the soil for trees to thrive is sporadic, causing tree lines to form. Downs and Racey (2006) found that bats preferred commuting to ponds on woodland edges and had better foraging opportunities near the tree lines. Therefore, bat species will utilize tree lines for commuting and foraging, preferring to stay out of open areas, such as fields, unless foraging opportunities arise. The species that were detected most frequently in the field were big brown bats, likely due to their wing loading and flight speed or due to interspecies competition.

There are species of bats that make annual migrations, while there are some species that are sedentary. In this study, the long-distance migrant silver-haired bat (*Lasionycteris noctivagans*) was recorded regularly during the spring and started to decrease throughout the summer and fall seasons. Silver-haired bats are known to migrate long distances in North America, and there have been studies to determine their stopover sites (McGuire et al. 2012). Silver-haired bats being predominantly present in the spring rather than the summer and fall could be because they were using the area as a stopover site along their migration route. Other species, such as the big brown bat, eastern red bat, and tricolored bat, were recorded in the spring, with an increase in the amount of recordings during the summer and then a decrease in the fall. This could be explained by these species being sedentary species going to roost for hibernation during winter. There were fewer recordings of the *Myotis* genus compared to other species, but this could be because species such as the little brown bat (*Myotis lucifugus*), Indiana bat (*Myotis sodalis*), and the gray bat (*Myotis grisescens*) are endangered species.

Conclusion

This study concludes that there are differences in species-specific activity levels across spatial and temporal dimensions. Habitat preferences could depend on the species-specific morphological and ecological attributes that ultimately determine the amount of bat species activity at a particular site. The use of open areas from species-specific bats needs more data to assess how certain bat species utilize open spaces in the central Appalachian regions. Even though the field sites were all close to one another, there was still a significant difference in species-specific activity levels showing that there is niche partitioning on a finer geographical scale. This study ultimately has the foundation to examine bat species composition in East Tennessee, allowing for more opportunities to update the region's current bat populations.

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