USING ACOUSTIC SURVEYS TO DETERMINE PRESENCE, HABITAT PREFERENCES, AND SPECIES COMPOSITION OF BATS (CHIROPTERA) IN EASTERN OKLAHOMA

By

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Abstract: The purpose of this study was to gather baseline data on species composition and estimates of abundance in bat communities of eastern Oklahoma so that population changes can be monitored if White Nose Syndrome becomes established in these areas. This project also provides data concerning foraging habitat preferences of bats. My hypotheses were that more bat calls would be recorded in forested habitats than in agricultural or urbanized landscapes and that species composition would vary according to habitat type and location of survey route. Also, species such as the evening bat (*Nycticeius humeralis*), eastern red bat (*Lasiurus borealis*), and little brown bat (*Myotis lucifugus*) would make up the majority of the calls collected from each route because they are the most common species in this general area. Acoustic surveys and ArcGIS were used to assess habitat use and species composition across six 48 km (30-mile) transects over 3 years. Buffers with radii of 1 km and 2 km were used to analyze landcover associated with recorded bat call locations. Habitat types, bat abundance, and species composition were evaluated for each route to determine preferences and species diversity. For both the 1 km and 2 km buffers, forested habitat had significantly higher bat numbers than agriculture, development, or water. Of the six routes, Grand Lake and Tar Creek had significantly fewer bats overall and the Nickel Preserve had the greatest overall diversity. *Perimyotis subflavus* was the most frequently encountered species followed by *Lasiurus borealis, Nycticeius humeralis, Myotis grisescens, Myotis lucifugus, Lasionycteris noctivagans, Eptesicus fuscus, Lasiurus cinereus, Corynorhinus townsendii*, and *Myotis septentionalis.* These data suggest that diversity and abundance of bats are likely influenced by amount of forested habitat. This information can be useful in conservation efforts by identifying important areas regularly used by large numbers of bats and making them a priority for conservation, thereby helping maintain healthy bat populations and overall biodiversity of their environments.

PREFACE

The first chapter of this thesis provides a literature review of relevant factors, including overviews of bat species, foraging habitat preferences, White Nose Syndrome, and acoustic surveys. The second chapter is written in the format appropriate for submission to *The Journal of Mammalogy*.

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CHAPTER I

LITERATURE REVIEW

Introduction to Bats –Bats belong to the order Chiroptera and are the only group of mammals capable of flight (Boyles et al. 2009). Chiroptera consists of 2 suborders known as Yangochiroptera, which includes microbat bat species, and Yinpterochiroptera, which is made up of the megabats and several microbat species. One of the differences between microbats and megabats is that microbats use echolocation whereas megabats typically do not. However, within the megabats, several species of the genus *Rousettus* have been known to use echolocation (Altringham 2011). As the second largest order of mammals, bats represent a significant proportion of mammalian biodiversity and play a major role in maintaining ecological stability in an ecosystem (Mickleburgh et al. 2002). Bats are nocturnal and volant, which makes them one of the most difficult vertebrates to study. Thus, relatively little is known about bat populations and their requirements for survival.

Currently it is estimated that there are around 1,200 bat species in the world, which makes up about 20% of all mammals (Altringham 2011; Wilson and Reeder 2005). Of the approximately 45 species of bats that occur in the United States, 7 of those are listed as federally endangered (United States Fish and Wildlife Service 2012). Oklahoma has 22 species of bats, roughly 49% of the total bat species found in the United States, 3 of which are listed as federally endangered: the Ozark Big-eared Bat (*Corynorhinus townsendii ingens*), the Gray Bat (*Myotis grisescens*), and the Indiana Bat (*Myotis sodalis*—Caire et al. 1989). All of the species in Oklahoma are members of the families Vespertilionidae and Molossidae and are in the suborder Yangochiroptera.

My study area includes 5 counties in northeastern Oklahoma (Ottawa, Delaware, Adair, Sequoyah, and Cherokee counties) that contain lands from The Nature Conservancy, Wildlife Management Areas, and National Wildlife Refuges. All of the species known from my study area are in the family Vespertilionidae and therefore are insectivorous, echolocating bats. Although Caire et al. (1989) show the ranges of 15 species to include the 5 counties represented in this study, searches of databases available through the Oklahoma State University Collection of Vertebrates (COV) and Mammal Networked Information System (MaNIS 2013) show that only 8 species have actually been recorded in this region (Table 1).

Many bats share preferred food types as well as foraging habitat; however, there are still many differences among species (Table 2). All of the bats previously recorded in northeastern Oklahoma prefer habitats that include rivers, streams, or ponds. Larger bats, like the big brown bat (*Eptesicus fuscus*), require more open spaces like cleared meadows and trees in pastures because their body size reduces flight maneuverability in densely wooded areas (Williams et al. 2002). Smaller bats utilize forest edges and canopies because they can fly more easily through cluttered areas (Williams et al. 2002). All the bats known to occur in this area eat at least some type of beetle and most consume moths as a major part of their diet. Many species also consume various types of flies and true bugs. The big brown bat is an important species in agricultural areas because it consumes agricultural pests such as cucumber and scarab beetles. Other bats, like the tri-colored bat (*Perimyotis subflavus*), help control mosquito populations. Overall, variability in preferred food types and foraging habitat make conservation of these species complex (Williams et al. 2002).

Habitat preferences –Habitat plays an important role in determining where bats forage, roost, and hibernate. Generally, bats in temperate zones tend to rely on forested areas for foraging, roosting, and protection from predators and weather (Fenton 1983; Smith and Gehrt 2010). On the other hand, even with the same insect abundance as a forested area, urbanized sites have very low feeding activity, suggesting that they do not provide all of the necessities required by bats (Jung and Kalko 2010).

The specific morphology of each bat species predicts how it uses various successional stages and structures of different habitats (Brooks and Ford 2005). One morphological feature that is especially important is wing structure. One way that wings vary among bat species is wing area relative to overall size of the bat, which is referred to as wing loading (Altringham 2011). For example, a large bat with relatively small wings will have a high wing loading. Larger bats with high wing loadings, such as hoary bats (*Lasiurus cinereus*) and silver-haired bats (*Lasionycteris noctivagans*), tend to forage over more open environments that are structurally less cluttered because their wing structure gives them lower maneuverability. Even with the presence of higher densities of insects, less maneuverable species still avoid cluttered environments. Species with low wing loadings and smaller bodies, like members of the genus *Myotis*, can maneuver more efficiently and thus utilize areas that are more cluttered such as closed-canopy habitats (Aldridge and Rautenback 1987; Broders et al. 2004; Brooks and Ford 2005; Nowak 1994).

Another feature that influences flight is aspect ratio, which is a measure of wing shape. A low aspect ratio means that the wing creates increased drag and is usually short and broad, whereas wings with a high aspect ratio have a long and narrow shape and reduced drag (Altringham 2011). Although bats tend to prefer more open forests, their actual use of an area also depends on insect abundance, wing-aspect ratios, and call frequencies (Altringham 2011; Barclay 1985; Fenton 1990; Menzel et al. 2005).

Bats tend to have high call frequencies ranging from 12-200 kHz depending on the species and its preferred habitat (Neuweiler 1990). Many vespertilionid bats, especially those with high aspect ratio wings and high wing loading like many *Lasiurus* species, forage above the forest canopy because there are fewer obstacles to encounter (Altringham 2011; Fenton 1990; Neuweiler 1990; Tuttle 1995). These bats typically have a call frequency of approximately 12-30 kHz because lower frequencies can travel over long distances, which is useful in an uncluttered environment (Altringham 2011; Neuweiler 1990; Tuttle 1995). Because insects tend to be more abundant closer to vegetation, some bats will forage in the open spaces between vegetation. These bats typically have slightly higher frequency calls because they must adjust for slower flight to avoid obstacles and shorter prey detection distances (Altringham 2011; Fenton 1990; Neuweiler 1990). This type of foraging is common in species like *Myotis lucifugus* and *Myotis leibii*, which use frequencies around 45 kHz (Mukhida et al. 2004). Other vespertilionids with low aspect ratio and low wing loading use gleaning as a foraging method. Gleaning refers to a bat’s ability to pick up prey from a surface. Gleaners such as *Myotis septentrionalis* forage in very cluttered environments, so they must use higher frequency calls of approximately 50 kHz in order to both maneuver and locate prey (Altringham 2011; Faure et al. 1993; Neuweiler 1990).

Although many bats forage and roost in forested habitat, many species also use man-made structures such as bridges and buildings as roosting sites (Agosta 2002). Although they typically roost in tree foliage, a study in Illinois showed that some eastern red bats (*Lasiurus borealis)* roost and forage in urban areas when prey and water are available (Mager and Nelson 2001). Some urban settings such as wooded parks, residential areas, and riparian corridors with mature trees and interspersed lawns and fields provide valuable roosting and foraging habitat for many bat species (Mager and Nelson 2001). Even though some species are able to exploit certain parts of urbanized sites, these areas still do not provide ideal conditions for bats. Urban landscapes have significantly lower bat species richness and diversity compared to protected areas such as wildlife refuges and management areas (Ávila-Flores and Fenton 2005; Gaisler et al. 1998; Geggie and Fenton 1985; Oprea et al. 2007; Oprea et al. 2009; Vaughan et al. 1997; Walsh and Harris 1996; Walsh et al. 1995).

In a study based on data collected during a national survey, Walsh and Harris (1996) analyzed foraging habitat preferences of vespertilionid bats. Experienced volunteers completed transects through a total of 32 different land classes. Their data verified that foraging activity over areas of intensive agriculture tends to be low (Walsh and Harris 1996). Although open landscape may be ideal for easy maneuverability, the low rate of foraging often was related to low levels of insect abundance rather than habitat preference (Walsh and Harris 1996). Interestingly, feeding rates on organic farms are typically higher than feeding rates on conventional farms possibly because lack of pesticide use leads to increased insect populations (Wickramasinghe et al. 2004). Conventional farms have a significant impact on abundance of nocturnal insects, which contributes to low levels of foraging activity by bats (Wickramasinghe et al. 2004). Ultimately, foraging bats need at least some natural land cover and riparian areas as both of these factors contribute to the presence of the invertebrate species that make up their diet (Lundy and Montgomery 2010).

White-Nose Syndrome—White-Nose Syndrome (WNS) is an emerging fungal disease that has caused mass mortality among bats in the United States. A recent study by Warnecke et al. (2012) provides evidence that the fungus associated with WNS is a novel pathogen to North America. Since first observed in the United States in 2006, the disease has spread across the eastern part of the country and into parts of Canada. It currently is documented in 26 states and 4 Canadian provinces and affects 9 species of bats (Bat Conservation International 2013, Fig. 1). Once becoming established in North America, spread of the disease is likely due to anthropogenic factors as well as migratory bat species transporting the pathogen from cave to cave (Frick et al. 2010; Lorch et al. 2011).

First observed in Howes Cave near Albany, New York, the disease is characterized visually by a white growth on the nose, ears, and wing membranes of infected bats (Blehert et al. 2009; United States Fish and Wildlife Service 2011). Mechanisms of the fungus are not known; however, WNS typically results in unusual behavior such as premature awakening from hibernation and flying in daylight hours during the winter, thereby contributing to loss of critical fat reserves and ultimately leading to death by starvation (Boyles et al. 2009; United States Fish and Wildlife Service 2011).

The fungus associated with WNS, *Geomyces destructans*, has a previously undescribed morphology (Blehert et al. 2009); however, recent findings suggest that *G. destructans* may have originated historically in Europe. Although the fungus has been found in Europe, deaths caused by WNS have not been observed there, suggesting European species may have developed a greater resistance or respond differently to infection from this fungus (Warnecke et al. 2012; Wibbelt et al. 2010).

The fungal hyphae are capable of eroding the epidermis of the ears and wings and invading hair follicles and associated sebaceous and sweat glands. The isolated fungus grows optimally between 5ºC and 10ºC (Blehert et al. 2009). Typical temperatures of WNS-infected hibernacula range from 2ºC to 14ºC, which provides optimal conditions for year-round growth of the fungus (Blehert et al. 2009). Population sizes in infected hibernacula have decreased by 30-99% annually with a regional mean decrease of 73% (Frick et al. 2010).

The disease has spread to the gray bat (*Myotis grisescens)* population in Missouri (Missouri Department of Conservation (MDC) 2010). Infection of this species is of great concern not only because gray bats are on the list of federally endangered species, but also because they are migratory. Migration of these bats may cause the disease to spread to other caves more rapidly than originally anticipated. In fact, *G. destructans* has been found as far west as Woodward, Oklahoma in cave myotis (*Myotis velifer*—R. Stark, pers. comm.). It is important to note that this finding was an isolated event of a single bat and although *G. destructans* is associated with WNS, its presence does not signify an outbreak of the disease. Most recently in March 2013, tricolored bats found in Lookout Mountain Cave and Sittons Cave in Georgia tested positive for *G. destructins* (Georgia Department of Natural Resources 2013).

In an attempt to slow the expansion of the disease, current response actions include limiting human access to all caves and thoroughly decontaminating equipment used in spelunking. Many caves are now gated to prevent people from possibly transferring the disease to other caves. Because some bat species are migratory, there is no known way to prevent bat-to-bat transmission of the disease. Should spread of the disease cause further population declines, unforeseen changes in ecosystem structure and function may occur and some currently endangered species may be at even greater risk of extinction (Frick et al. 2010). Therefore, it is imperative to gather baseline data on bat species in areas that are likely to be in the path of the spreading disease so that population changes can be monitored.

Based on current trends, Oklahoma has the potential to be the next state infected with WNS. My sites in eastern Oklahoma are directly in the path of this disease's progress across northeastern North America. Fortunately, because the disease has taken several years to spread from New York south to Missouri, we have begun collecting baseline data on eastern Oklahoma bat species. However, should the disease continue to spread southwestward, it is only a matter of time until bats in Oklahoma become exposed to White Nose Syndrome.

<u>Acoustical Surveys</u>—Use of ultrasonic bat detectors for acoustic surveying is an accepted method to monitor bat communities (Lance et al. 1996). Aside from being low-cost and easy to set up, bat detectors enable researchers to monitor bats on a much less invasive

level than traditional methods of netting and handling bats to gather data (Lance et al. 1996). Bat detectors like the Anabat ZCAIM (Zero-Crossings Analysis Interface Module) or SD-1 gather acoustic calls that provide information on species composition and population numbers without disturbing the bats.

The Anabat detection system is designed to produce a real-time display showing frequency and duration information of individual calls. As a zero-crossing detector, the Anabat ZCAIM is triggered when the amplitude of a recorded call crosses a certain threshold. For example, each call has air pressure waves that alternate above and below the average air pressure. These values are converted into electrical signals by the Anabat microphone and the resulting zero-crossings represent points where the electrical signal crosses over the average value from positive to negative and vice-versa. Zero-crossings are used to analyze the frequencies of pulses in bat calls (Skowronski and Fenton 2009).

An entire echolocation sequence contains three different phases: a search call used to search for and locate prey, an approach call used once prey is detected, and a feeding buzz used right before capture (Altringham 2011; Jonker et al. 2010; Murray et al. 2001). As a bat gets closer to its prey, the pulses in the call become shorter and more frequent to increase precision of capture (Jonker et al. 2010; Moss et al. 2006). Often, the search-phase portion of a call is used for identification because these calls usually have species-specific characteristics, have a consistent structure, and are used more frequently by foraging bats than any other type of call (Murray et al. 2001). Each species of bat has a unique search-phase call that can be identified based on shape, frequency, slope, and duration. Calls differ among species because different species have adapted to various habitats and foraging situations (Pfalzer and Kusch 2003). Even bats of the same species may have variation in their search-phase call if they are foraging in different habitat types (Murray et al. 2001).

To identify collected calls, software programs like Analook can be used to view the calls on a graph showing call frequency over time and also sort and save captured calls (Titley Electronics, Balina, NSW, Australia). Minimum and maximum frequencies (kHz) are used as identifying characteristics for determining bat species. For example, the little brown bat (*Myotis lucifugus*) tends to have a high slope, nearly vertical call with a minimum frequency of approximately 40 kHz (Fig. 2). Bats with lower frequencies around 20 kHz tend to forage in open areas whereas bats with frequencies that vary from 30-60 kHz tend to forage in more cluttered areas (Pfalzer and Kusch 2003). Many *Myotis* spp. have minimum call frequencies around 40 kHz, which makes them very difficult to distinguish from each other (Murray et al. 2001). Often, there are too many call files to go through individually, so call libraries can be created to make the process faster. Call libraries have calls that were collected from positively identified bats. A filter can then be used to go through all of the collected call files and pull out calls that correspond to that species. C. Ryan Allen from Missouri State University has created an automated software program (BatCall-ID—BCID) with its own call library that interacts with the Analook software (C. R. Allen in litt.). BCID uses a specific proprietary algorithm to interpret the data and determine the most likely bat represented by the call file. Twenty to forty call files per second can be analyzed for numerous bat species with this new software.

Equipment like the Anabat allows us to collect large amounts of data in a very short amount of time. Additionally, detectors can be used for both active and passive monitoring. Passive monitoring is often used to determine which species of bats utilize a specific area such as a cave or farm. The detector can be left in the field for weeks or even months except for occasional downloading of data. It is possible to set up a solar panel so that the batteries in the Anabat do not even need to be recharged. This way, the device can be left at a cave entrance or any other location to monitor bat activity and the species that utilize the cave or other habitat of interest. Active monitoring typically requires a roof mount microphone. Using a roof mount allows researchers to collect calls via mobile transects through multiple habitat types. Active monitoring with the detector enables scientists to also cover a much larger geographic area compared to other methods of monitoring such as passive monitoring or mist netting. With these capabilities, the scope of research can be greatly expanded, making long-term monitoring much more feasible (Skowronski and Fenton 2009).

Objectives—The main objective of this study was to conduct intensive 3-year acoustic monitoring surveys of the bat species of eastern Oklahoma. Acoustic calls were spatially marked and analyzed in ArcGIS to determine preferred foraging habitat types. A secondary objective was to gather baseline data on species richness and presence of bat communities so that comparisons of population trends can be made if White-Nose Syndrome becomes established in eastern Oklahoma.

My hypotheses were that more bat calls would be detected in forested habitats than in agricultural or urbanized landscapes. I also hypothesized that species composition would vary according to habitat type and location of survey route. Also, species such as the evening bat, eastern red bat, and little brown bat would make up the majority of the calls collected from each route because they are the most common species recorded for this general area (MaNIS 2013). Mammal Networked Information System (MaNIS) is part of the National Biological Information Infrastructure supported by the National Science Foundation and provides access to many specimen records from museum collection databases for over 30 natural history museum collections.

Because of the quick onset of WNS, there has been little opportunity to gather baseline data on sizes of bat populations before the colonies become infected. Additionally, while there is population information available, it typically focuses on endangered bat species. Therefore, data that can be used as historical references are very limited. We will be unable to determine the ultimate severity of WNS unless baseline data are available. More research is needed to gather further understanding about the more common bat species of the United States. This project will gather baseline data on abundance and species composition of bat communities of eastern Oklahoma so that comparisons can be made if WNS becomes established in these areas. Data concerning foraging habitat preferences of bats will be useful in conservation efforts by identifying important areas regularly used by large numbers of bats, thereby helping to maintain healthy bat populations and overall biodiversity of their environments.

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CHAPTER II

USING ACOUSTIC SURVEYS TO DETERMINE PRESENCE, HABITAT PREFERENCES, AND SPECIES COMPOSITION OF BATS (CHIROPTERA) IN EASTERN OKLAHOMA

ABSTRACT—The purpose of this study was to gather baseline data on species composition and estimates of abundance in bat communities of eastern Oklahoma so that population changes can be monitored if White Nose Syndrome becomes established in these areas. This project also provides data concerning foraging habitat preferences of bats. My hypotheses were that more bat calls would be recorded in forested habitats than in agricultural or urbanized landscapes and that species composition would vary according to habitat type and location of survey route. Also, species such as the evening bat (*Nycticeius humeralis*), eastern red bat (*Lasiurus borealis*), and little brown bat (*Myotis lucifugus*) would make up the majority of the calls collected from each route because they are the most common species in this general area. Acoustic surveys and ArcGIS were used to assess habitat use and species composition across six 48 km (30-mile) transects over 3 years. Buffers with radii of 1 km and 2 km were used to analyze landcover associated with recorded bat call locations. Habitat types, bat abundance, and species composition were evaluated for each route to determine preferences and species diversity. For both the 1 km and 2 km buffers, forested habitat had significantly higher bat numbers than agriculture, development, or water. Of the six routes, Grand Lake and Tar Creek had significantly fewer bats overall and the Nickel Preserve had the greatest overall diversity. *Perimyotis subflavus* was the most frequently encountered species followed by *Lasiurus borealis*, *Nycticeius humeralis*, *Myotis grisescens*, *Myotis lucifugus, Lasionycteris noctivagans*, *Eptesicus fuscus*, *Lasiurus cinereus, Corynorhinus townsendii*, and *Myotis septentionalis.* These data suggest that diversity and abundance of bats are likely influenced by amount of forested habitat. This information can be useful in conservation efforts by identifying important areas regularly used by large numbers of bats and making them a priority for conservation, thereby helping maintain healthy bat populations and overall biodiversity of their environments.

Key words: Bats, echolocation, landscape scale, monitoring, species richness, White Nose Syndrome.

INTRODUCTION

Habitat selection by bats is difficult to evaluate because the habitat selected can vary depending on the spatial scale used in the study (Gehrt and Chelsvig 2003). Often habitat selection is based on proximity to other resources such as water or hibernacula, but can also depend on climate or human-induced land changes (Gehrt and Chelsvig 2003; Johnson et al. 2008). Habitat also plays an important role in determining where bats forage and roost. Although bats tend to prefer more open forests, their actual use of an area varies with insect abundance, wing-aspect ratios, and call frequencies (Altringham 2011; Barclay 1985; Menzel et al. 2005).

Aside from forests, bats roost in man-made structures such as bridges and buildings (Agosta 2002). Species such as the big brown bat (*Eptesicus fuscus*) are generalists in choice of foraging and roosting habitats, which allows them to exploit resources even in urban settings (Johnson et al. 2008). Other species like the Indiana bat (*Myotis sodalis*) are more specialized and prefer habitats with more cover such as forests (Sparks et al. 2005). Although some urban settings such as wooded parks, residential areas, and riparian corridors with mature trees and interspersed lawns and fields offer resources that provide valuable roosting and foraging habitat for many bat species, very few bat species are able to use these resources efficiently and species diversity tends to be low in these areas (Mager and Nelson 2001). In comparison, both species richness and diversity are significantly higher in protected areas such as wildlife refuges and management areas since resources are more abundant (Ávila-Flores and Fenton 2005; Gaisler et al. 1998; Oprea et al. 2009).

Similar to urban areas, foraging activity over areas of intensive agriculture tends to be lower than activity in forested habitats. Although this open landscape may be ideal for easy maneuverability, the low rate of foraging can often be related to low levels of insect abundance rather than habitat preference (Walsh and Harris 1996). However, riparian buffers between fields or along roadsides have been found to be used preferentially by some bat species (Downs and Racey 2006). These vegetation corridors often have high densities of insects and are best suited for echolocation, along with providing shelter from harsh weather conditions (Downs and Racey 2006). Riparian corridors along water are also considered important. Walsh and Harris (1996) showed that activity is higher over rivers next to woodlands compared to treeless stretches of rivers. Ultimately, foraging bats need at least some natural land cover and riparian areas as both of these factors contribute to the presence of the invertebrate species that make up their diet.

White-Nose Syndrome.—White-Nose Syndrome (WNS) is a disease of hibernating bats in North America and is associated with a psychrophilic fungus. First observed in Howes Cave near Albany, New York, the disease is visually characterized by a white fungal growth on the nose, ears, and wing membranes of affected bats (Blehert et al. 2009). Since the first observation in 2006, the disease has spread southwest across the country into 26 states and north into 4 provinces in Canada, and affects at least 9 species of hibernating bats (Bat Conservation International 2013). The spread of WNS is both rapid and severe, resulting in mortality rates up to 99% in infected hibernacula. Now that WNS is established in North America, the current spread of the disease is likely due to anthropogenic factors such as moving contaminated equipment from cave to cave, as well as migratory bat species transporting the fungus from cave to cave (Frick et al. 2010).

Initially, it was not known if the fungus associated with WNS (*Geomyces destructans*) was the direct cause of the disease. However, recent research confirms that *G. destructans* is the primary pathogen and causative agent of WNS. Lorch et al. (2011) determined that healthy bats will contract WNS from exposure to *G. destructans* and that WNS can be transmitted from infected bats to healthy bats through direct contact. WNS typically results in unusual behavior such as premature awakening from hibernation and flying around in daylight hours during the winter. thereby contributing to the loss of critical fat reserves and ultimately leading to death by starvation (Boyles et al. 2009).

Because the fungus can be transmitted through direct contact between bats, one of the concerns is that it will be transported faster if a migratory bat becomes infected. Unfortunately, the disease has spread to the gray bat (*Myotis grisescens)* population in Missouri (Missouri Department of Conservation (MDC) 2010). Infection of members of this species is of great concern not only because they are migratory, but also because gray bats are on the list of federally endangered species. The migration of these bats may cause the disease to spread to other caves more rapidly than originally anticipated. In fact, *G. destructans* has been found as far west as Woodward, Oklahoma in cave myotis (*Myotis velifer*—R. Stark pers. comm.).

In an attempt to slow the expansion of the disease, many caves are now gated to prevent people from possibly transferring the disease to other caves. However, there is no known way to prevent spread of WNS via bat to bat contact. Should the spread of the disease cause further population declines, unforeseen changes in ecosystem structure and function may occur (Frick et al. 2010). Therefore, it is imperative to gather baseline data on bat species in areas that are likely to be in the path of WNS so that any changes in populations or community structure can be monitored.

Bat detectors.—Using ultrasonic bat detectors for acoustic surveys has become a widely accepted way to monitor bat communities (Lance et al. 1996). Aside from being easy to use, bat detectors offer many advantages over mist-netting. Detectors can be used over much greater spatial and temporal extents and in open habitats where mist-netting is not possible (Rodhouse et al. 2011). Bat detectors like the Anabat ZCAIM (Zero-Crossings Analysis Interface Module) or SD-1 gather acoustic calls that provide information on species composition and population numbers without disturbing the bats. One of the drawbacks is the difficulty of identifying bat calls to the species level.

The Anabat detection system is designed to produce a real-time display showing information on frequency and duration of individual calls. Each file consists of a call with different pulses that are emitted by the bat to locate prey. The search phase part of the call sequence is used to identify species because it is species-specific and can be identified based on its shape, frequency, slope, and duration. Equipment like Anabat allows collecting of large amounts of data in a short amount of time. This equipment also has the capability of being run on solar powered batteries to collect data over a relatively long period of time. With these capabilities, the scope of bat research can be greatly expanded, making long-term monitoring more feasible (Skowronski and Fenton 2009).

This paper presents an analysis of selection of foraging habitat by bats in eastern Oklahoma based on data collected May-October of 2010, 2011, and 2012. Comparisons of the patterns of habitat use at two different scales were used to determine if habitats were consistently used by the bats at both scales. The primary aim of this project was to identify key foraging habitats to provide a foundation for future conservation efforts. A secondary goal for this project was to collect baseline data on species diversity and abundance that will facilitate comparisons of bat populations before and after infection if WNS should reach eastern Oklahoma.

My hypotheses were that more bat calls would be detected in forested habitats than in agricultural or urbanized landscapes. I also hypothesized that species composition would vary according to habitat type and location of survey route. Also, species such as the evening bat, eastern red bat, and little brown bat would make up the majority of the calls collected from each route because they are the most common species in this general area (MaNIS 2013).

METHODS

Site Description.—Acoustic data were actively collected once monthly during May, August, September and October and twice monthly during June and July from six 48 km (30-mile) mobile transects across 5 Oklahoma counties for 3 years (2010-2012 – Figs. 3-5). The northern-most route is separated from the southern-most route by approximately 160 km. Site selections were intended to cover a large area of northeastern Oklahoma over locations that were of specific interest to the U.S. Fish and Wildlife Service and that included a range of habitat types including forest, agricultural land, urban areas, and bodies of water. The U.S. Fish and Wildlife Service was interested in these surveys because Oklahoma has limited baseline data on species composition and population sizes of bats within the state. The specific routes were restricted to roadways and also included areas used by endangered species (*Myotis grisescens, Corynorhinus townsendii ingens*, and *Myotis sodalis*), areas with known hibernacula or maternity caves, and areas where relatively little is known about the inhabiting bat populations. Many of the routes are within the Ozark Plateau, which covers much of eastern Oklahoma and was historically described as a hilly area that had been timbered (Nelson, 1997; United States Fish and Wildlife Service 2009). In thinly timbered areas, mean tree density was near 20 trees/ha (Nelson 1997). This region also has fire dependent savanna habitats interspersed among areas of closed forest and open prairie (Nelson 1997).

The northern-most route traverses Tar Creek Superfund Site (Fig. 3). This area is contaminated because of historic zinc and lead mining, and approximately 75 billion kilograms of chat remain in the area (Environmental Protection Agency 2011; Sonwalkar et al. 2010). Prior to mining, this region had some of the cleanest water and most pristine prairies in Oklahoma (Sonwalkar et al. 2010). Now, there is very little vegetation and many abandoned mining operations (Environmental Protection Agency 2011; Sonwalkar et al. 2010). South of the Tar Creek route is another route that runs near Grand Lake in Grove, Oklahoma (Fig. 3). Grand Lake is an 18,800-ha reservoir that provides hydropower, flood control, and recreation (Stancill et al. 1989). The habitat on the eastern side of the lake consists of oak and hickory stands that are characteristic of the Ozark Plateau region. The west side of the lake is dominated by tall grasses characteristic of the Cuestea Plains. Bottomland hardwoods in the area are dominated by eastern cottonwood, sycamore, willow, elm, and maple species (Stancill et al. 1989).

Sally Bull Hollow and January-Stansbury routes are near federal lands of the Ozark Plateau National Wildlife Refuge (NWR). The Ozark Plateau NWR is found within the Oak-Hickory Forest Ecoregion with karst topography, steep hills, incised valleys, and prominent bluffs. Because much of the drainage is underground, there are numerous caves in the area making this habitat unique and important to local bat species (United States Fish and Wildlife Service 2009). The January-Stansbury route cuts through Lake Eucha State Park and the town of Jay, OK (Fig. 4). The Sally Bull Hollow route also goes through the Ozark Plateau Wildlife Management Area (WMA) near Stilwell, Oklahoma (Fig. 5).

The fifth route encompasses the perimeter of the Nature Conservancy's J.T. Nickel Preserve, just north of Tahlequah, Oklahoma (Fig. 4). The Nickel Preserve is a conservation area in the Ozarks that has dense oak-hickory stands along with pine woodlands, oak savannas, shrublands, and prairies (The Nature Conservancy 2011). Although it has a variety of native habitats, it is already invaded by species such as sericea lespedeza (*Lespedeza cuneata*—The Nature Conservancy 2011). South of the Nickel Preserve, the sixth route passes through the Cookson WMA (Fig. 5). This WMA is comprised of meadows and clearings along with dense stands of oak-hickory and short leaf pines in a relatively hilly area (Allen 2011).

Acoustical Surveys.—Sampling dates were selected based on the protocol developed by Eric Britzke and Carl Herzog (2009) when wind speeds were under 24 kph (15 mph) and there was no precipitation in the forecast. Only one route was driven per night. I began surveys 15-30 minutes after official sunset according to the United States Naval Observatory, which is when substantial bat activity usually begins (Brooks and Ford 2005). Each route was driven at approximately 32 kph (20 mph) to minimize the chance of recording multiple calls from a single bat (Britzke and Herzog 2009) and covered a range of habitat types including urban, agriculture, streams, and forests. Acoustic calls were collected using a microphone roof mount attached to an Anabat ZCAIM, which was also attached to a GPS unit. The detector recorded sounds from 4-200 kHz at an average detection distance of 18 m from the Anabat unit microphone. The Anabat ZCAIM sensitivity was maintained at a level of 6 out of 9 as this setting helps minimize background noise and still records most bat calls (Brooks and Ford, 2005). The ZCAIM stores spatial coordinates from the GPS unit continuously while simultaneously recording bat calls.

Data Processing.—After completion of each route ZCAIM data were downloaded using cfcread software (Titley Electronics, Balina, NSW, Australia). The Anabat files were manually sorted into “Bat” and “Noise” files using the Analook software (Titley Electronics, Balina, NSW, Australia). “Noise” resulted from background sounds such as wind or insects. While bat calls have distinct pulses and fall within a specific frequency range, background noise appears as a continuous scattered arrangement of points and occurs at very low frequencies. Coordinates from the GPS unit were imported into ArcGIS where each route was mapped. Each bat call also had associated latitudes and longitudes, which were imported into ArcGIS and plotted along each route.

After calls were sorted, I imported each route and call files into ArcGIS. Habitat was quantified using land cover data available from the United States Geological Survey (USGS 2006). I used a multi-scale approach to estimate the habitat type most utilized by foraging bats. I placed 2 buffers around the location of each call: one with a 1 km radius and the other with a 2 km radius. The 1 km buffer shows the immediate habitat use of each bat. Because common bat species like *Eptesicus fuscus* and *Lasiurus borealis* tend to travel an average distance of 2 km from their roosting site to forage, these buffers should reflect relevant spatial scales of habitat selection (Brigham 1991; Elmore et al. 2005). Within each buffer, I determined the largest habitat type by using ArcGIS area calculations. Habitat variables included agriculture, forest, water, and developed areas because these were the general habitat types that fell within the call buffers.

Data Analysis—Because each recorded call represents a single unique bat, I calculated the number of bats and number of species observed in a given night and compared these numbers over time to establish an estimated presence for a certain area. Bat calls were identified to the species level using the BatCall-ID program developed by C. Ryan Allen from Missouri State University. This program uses unique call characteristics such as shape, slope, and minimum and maximum call frequencies for species identification.

Calls were required to have a minimum of 5 pulses within 15 seconds for identification. Any call with fewer than 5 pulses was not included in subsequent analyses.

Overall species diversity was calculated using Simpson's Diversity Index since this index is considered to be a strong measure of diversity (Rex et al. 2008). Other indices that calculate evenness are actually derived from the reciprocal Simpson Index, which is why no other indices were calculated (Heip et al. 1998). The general linear model (GLM) was used to determine if there were differences among bat presence, habitat type, and route along with comparing species to habitat type and route. If significant differences were found, then Duncan's multiple comparisons procedure was used to determine where those differences occurred. All statistical tests were run using SAS 9.3 (©SAS Institute Inc., Cary, NC, USA).

Because Oklahoma has been experiencing a severe drought during 2 of the 3 years of my study, I also examined mean temperature and rainfall for the nearest weather stations available through the Oklahoma Mesonet environmental monitoring stations (www.mesonet.org).

RESULTS

GLM showed that, for the 1 km buffer, abundance was significantly different among habitat types (*df* = *3*, *F* = *9.98*, *P* = 0.0003). Duncan's procedure showed that there was no significant difference in bat abundance among habitats consisting of development, water, or agriculture. However, bats used forested areas significantly more than all other habitat types (Fig. 6). There also was a significant difference in abundance among habitat types at the larger scale of the 2 km buffer (*df* = *3*, *F* = *10.79*, *P* = 0.0002). Duncan's procedure again indicated that there was no significant difference among developed, water, or agricultural habitats, but bat abundance was significantly greater in forested habitats (Fig. 7).

I also tested the difference in the combined 3-year total of bat numbers among route locations because the greatest distance between routes was approximately 160 km and habitat types may differ within that distance. There was a significant difference in bat abundance among route locations (*df* = *5*, *F* = *6.69*, *P* < 0.0001). Duncan's procedure showed that the Grand Lake and Tar Creek routes had significantly fewer bats than the other four routes, but did not significantly differ from each other (Fig. 8). Cookson, January-Stansbury, Nickel Preserve, and Sally Bull Hollow were not significantly different from each other (Fig. 8). I calculated the total percentage of each habitat type along each route for both buffer sizes along with the percentage of bat calls recorded for that route to determine if routes differed in habitat composition. These results showed that forest was the predominant habitat type for all routes except Grand Lake and Tar Creek at both 1 km and 2 km buffers (Table 3). Bats were more abundant in forested areas for all routes and all buffer sizes except for Grand Lake and Tar Creek at both 1 km and 2 km buffers.

I also compared abundance among years and among months within years. The yearly comparison showed that there was a significant difference among years ($df = 2, F = 7.31, P = 0.0011$). Duncan's procedure showed that 2010 had more bat activity than 2011 or 2012 (Fig. 9). The monthly analysis showed that there was also a significant difference in bat numbers among months ($df = 5, F = 4.4, P = 0.0011$). Duncan's procedure showed that July and August had significantly more bat activity than May, June, September, and October (Fig. 10).

Over the 3 field seasons, a combined total of 4,664 calls were recorded; 1,826 of which fit criteria for identification to the species level. Within those calls, 10 species were identified, with *Perimyotis subflavus* and *Lasiurus borealis* making up the majority of the calls (about 53% and 18%, respectively). There was also a group marked "unknown" for calls that could not be identified by the BatCallID program (3.5%–Table 4). *P. subflavus* was the most common species encountered for every route followed by *L. borealis* and *N. humeralis*. Overall, the least common species were *M. septentionalis, L. cinereus,* and *E. fuscus* (Table 4). *P. subflavus* was also the most common species in every habitat type for both buffer sizes followed by *L. borealis* (Table 5). *M. grisescens, L. cinereus, E. fuscus, M. septentionalis, C. townsendii,* and *Lasionycteris noctivagans* were never encountered in developed areas on any of the routes (Table 5). The Simpson's Diversity Index for bats among routes was greatest for the Nickel Preserve (0.703) and least for Sally Bull Hollow (0.520—Table 4). The Simpson's Diversity Index for bats among habitat types was greatest for forested areas (0.679) and least for water (0.267—Table 5). Average monthly temperatures and total rainfall for May through October during 2010-2012 are given in Tables 6 and 7 respectively.

DISCUSSION

The primary goal of this study was to investigate the relationship between bat abundance and habitat type at two different scales. I hypothesized that more bat calls would be recorded in forested habitat than in agricultural or developed landscapes. Results were similar at the 1 km and 2 km scales, with forested habitats being used significantly more by bats than any other category of habitat, followed by agriculture, water, and development. It is important to note that in most cases forest was also the most commonly encountered habitat along the routes and that not all habitats were equally represented. Cookson, Sally Bull Hollow, Nickel Preserve, and January-Stansbury were characterized by a large amount of forest, whereas Grand Lake and Tar Creek were characterized by a large amount of agriculture (Table 5). However, of the habitats included in this study, forests likely provide the greatest amount of resources for bats such as foraging habitat, roosting habitat and escape cover from predators, which could also explain the high usage by bats (Gehrt and Chelsvig 2003).

While bat numbers were significantly lower in agricultural areas than forested areas, this habitat type still had the second highest mean number of bats recorded. Two possible explanations are that agriculture was more prevalent than water or developed areas or that agriculture provides more foraging resources for bats. However, pesticide use on crop fields may eliminate or contaminate the insect food source causing bats to either not forage in those areas or possibly suffer detrimental effects from exposure to pesticides or ingestion of pesticide-contaminated insects. Thies and McBee (1994) showed that organochlorine pesticides can accumulate in the body tissues of insectivorous bats, and can be related to population declines. There are also differences in bat abundance between organic farms and conventional farms, with organic farms having higher abundance (Isenring 2010). Therefore, it is likely that bat abundance in agricultural areas is related to total agriculture area and not resources. Another explanation is the proximity of roosting habitat to foraging habitat. Even though bats prefer to have at least some cover and insect abundance is greater in forested areas, agricultural fields may be closer to their roosting sites (Johnson et al. 2008). It is possible that distance to hibernacula is more important than the effects of development or risk of open, unprotected habitats (Johnson et al. 2008).

Johnson et al. (2008) suggest that reasonable proximity to hibernacula probably accounts for higher abundances in certain areas at both the landscape and home range scales. They also propose that habitat may play a role in the presence or absence of bats. It is likely that close proximity to a hibernaculum is most important, followed by large amounts of forest cover and then by low degrees of urbanization. Other studies support this conclusion having found that there was a strong, negative relationship between distance from forest edge and bat activity (Gehrt and Chelsvig 2003). Because many of the species in my study area roost in trees or caves, Gehrt and Chelsvig's (2003) results relate to my findings in that the majority of the bats were found in forested areas followed by open pastures, then by developed areas.

Developed areas were expected to have little to no bat activity, which was supported by the results. Not only was the percent of developed area small overall, but urbanized areas likely do not provide as much as other habitats in the way of food resources (Gehrt and Chelsvig 2003). However, there were at least some bat calls that were recorded in urbanized areas. It is possible that urban areas are similar to patchy habitats utilized by bats because they often have woodland edges and trees dispersed throughout the landscape (Fabianek et al. 2011; Gehrt and Chelsvig 2003). Developed areas also provide artificial roosting habitat such as attics that compensate for the lack of trees. There have also been studies showing higher concentrations of bats around streetlights foraging on flying insects that are attracted to the light (Hickey et al. 1996).

The lack of foraging bats around open water was an unexpected result because bats are often associated with water (Fukui et al. 2006). I likely found so few bats around water because water does not cover much are within the selected buffer sizes at the landscape scale. If I had used a smaller buffer size to analyze only the immediate surroundings of any particular bat call location, it is likely that water would become more important. Because the buffers for this project were chosen for a larger scale approach, there were very few bats classified as using water for foraging. Although water had significantly fewer bat calls recorded than forest, the flux of aquatic insects emerging from streams is one of the most important factors affecting the presence or absence of bats along waterways (Fukui et al. 2006).

Because there were different proportions of the habitat types in each route, my goal was to determine if the routes differed in number of bats. There was a significant difference in bat abundance among the routes. These differences may be related to the landscape history of each route. Cookson had the highest abundance followed by January-Stansbury, Nickel Preserve, and Sally Bull Hollow, whereas Grand Lake had a low abundance of bats followed only by Tar Creek. Cookson and January-Stansbury likely had the highest mean abundance because there are known hibernacula and maternity caves in those areas. While the hibernacula can ensure higher numbers of bats, the maternity caves alone can double the population when pups are old enough to fly in mid to late summer (Horn and Kunz 2008). I detected the largest numbers of bats during July and August of each year, most likely a reflection of the first appearance of newly volant young. The mean number of bats for Nickel Preserve was similar to that of January-Stansbury, possibly because both have lands that are protected from development. While there is some development along the January-Stansbury route, the maternity cave and amount of forested habitat may offset the negative effects of the development. Sally Bull Hollow also had a large number of bats, which again can likely be attributed to hibernacula, some protected lands, and the abundance of forest in that area. Even though the Grand Lake route runs along the edge of a large body of water, it still had significantly fewer bats than four of the five other routes. This likely is explained by the greater amount of agricultural land and decrease in forests as the route progresses southward. This route also goes through an area of considerable human disturbance due to recreational use around and on Grand Lake. These data support conclusions of Evelyn and Stiles (2003) that even if essential resources like water are available, bats will not inhabit areas if there are not optimal conditions for activities such as roosting habitat or isolation from human disturbance. Tar Creek, as was expected, had the lowest mean abundance. Not only was the Tar Creek route though a Superfund site, but it also had higher amounts of open habitat and a greater degree of development, which all likely contribute to the low number of bat calls observed along that route.

Because habitat types and routes all showed significant differences I calculated the percent of each habitat type along the routes using the 1 km and 2 km buffer sizes and calculated the corresponding percentage of bat calls that occurred in that particular habitat. Cookson, January-Stansbury, Nickel Preserve, and Sally Bull Hollow had a high percentage of forested habitat (over half) and a high percentage of bat calls that occurred in forested habitat (over half). On the other hand, Grand Lake and Tar Creek had a higher percentage of agriculture than forest; however, the percentage of bat calls that occurred in agriculture was 50% or less. These results make it difficult to determine if bat calls occurred in forested areas because they prefer forests or because forest made up the greatest area. Tar Creek showed the most interesting data with forest making up 18.1% and 17.3% of the total area for the 1 km and 2 km buffers respectively. With such a low total area percentage, 38.3% and 43.3% of bats still occurred in the forested areas, which suggests that at least in the Tar Creek area, bats strongly prefer forest to any other habitat type (Table 3).

Throughout the course of this project, weather became an important factor, with record temperatures and drought occurring for two out of three years. Based on data available through the Oklahoma Mesonet environmental monitoring stations (www.mesonet.org), the average monthly temperatures for 2010 were never more than 2.6°C higher than the 30-year normal (Table 6). In 2011, the average monthly temperature was higher than the 30-year normal for every month except May by a maximum of 4.2°C. The average monthly temperature in 2012 was higher than the 30-year normal for every month except October with the greatest difference being 2.7°C. Precipitation for 2010 was above the 30-year normal during the spring and fall months (May, September, and October) and slightly below average during the summer months (June, July, and August). In 2011, rainfall was below the 30-year normal for all months except May (Table 7). Rainfall in 2012 was below the 30-year normal for every month during my field season. In 2011 and 2012, the lowest amount of rainfall occurred in July accumulating to only 1.5 cm and 1.9 cm, respectively. Considering these weather patterns, it was important to determine if bat abundance fluctuated from year to year or from month to month. The year with the lower temperatures and greater rainfall, 2010, also had the highest bat numbers. The following two years, 2011 and 2012, had significantly fewer bats than 2010. Mean abundance for 2012 was less than that of 2011. Based on the weather trends, these decreases are likely due to a lack of water and high temperatures that may have depleted water resources and killed off much of the aquatic insects that bats rely on for food. However, I cannot say if these decreases are related to loss of food resources and therefore actual deaths or if bats simply moved to a more favorable area.

My second hypothesis was that species composition would vary according to habitat type and location of survey route. I also hypothesized that species such as the evening bat, eastern red bat, and little brown bat would make up the majority of the calls recorded from each route because they are considered common species within my study area. Species composition varied among habitat types with water having the lowest bat diversity and forest having the highest diversity. As mentioned previously, water does not cover much area at the landscape scale, so this low number is likely not a good representation of the true bat diversity for this habitat type. However, 24 individuals of *P. subflavus* were encountered within areas of water whereas the 3 other species associated with water only had 1 or 2 individuals encountered in this habitat. Therefore, the dominance of *P. subflavus* also likely contributed to the low diversity score for water habitat. I expected forested habitat to have greater diversity because many of the bat species that are known to occur in my research area are capable of maneuvering through cluttered environments and also take advantage of the cover that forests provide (Williams et al. 2002). Agricultural and developed landscapes had the second and third highest diversity, respectively. Some of the species identified, such as *E. fuscus*, are known to forage over agricultural areas, which may explain the diversity score for agriculture (Williams et al. 2002). Interestingly, the developed areas had fewer total bats than water, and yet developed habitat received a higher diversity score. This outcome is due to the fact that developed areas were not dominated by any one particular species.

Simpson's Diversity Index showed that Nickel Preserve had the highest diversity of all routes followed by Cookson, January-Stansbury, Grand Lake, Tar Creek, and Sally Bull Hollow. The Nickel Preserve route had 8 of the 10 species recorded with a relatively even distribution of individuals among species. Cookson also had 8 of the 10 species recorded, however, the distribution was not as even as for the Nickel Preserve, explaining the lower diversity score (Table 4). Sally Bull Hollow had an unexpectedly low score of 0.520 even though it also had 8 of the 10 recorded species. This difference is because Sally Bull Hollow was dominated by *P. subflavus* and had very few individuals for the other species recorded.

Overall, every route was dominated by *P. subflavus, L. borealis,* and *N. humeralis*, which supports my hypothesis and the data collected from MaNIS and the Oklahoma State University COV. I also recorded calls from *L. cinereus, M. lucifugus,* and *Lasionycteris noctivagans*, which were not previously documented in the study area by either MaNIS or the Oklahoma State University COV. However, *M. velifer* has previously been documented in my research area, but was not recorded during my research. Based on other range maps and descriptions, it is unlikely that *M. velifer* actually occurs in eastern Oklahoma and that record may have been a misidentification (Ismail 2000; Smithsonian Institution 2012). Of the total species recorded, there were few *L. cinereus, E. fuscus, M. septentrionalis,* and *C. townsendii*. The ranges of the latter 2 species do not reach far into Oklahoma, so my routes may not have passed directly through areas that they typically inhabit (Smithsonian Institution 2012). However, I did record some calls that were identified as those species, which can be supported by the documentation provided by MaNIS and the Oklahoma State University COV. The ranges for *L. cinereus* and *E. fuscus* are widespread across the United States, so it is difficult to say why so few individuals were recorded. A possible explanation could be that since both of these species are relatively large, they were foraging in more open areas such as agricultural fields or above tree canopies that were out of range of the Anabat unit. If this is the case, then these species may be more abundant than is suggested by my data.

Future research should place greater emphasis on analysis of lake and riparian habitat because of their importance in supplying food resources in the form of emerging aquatic insects. Because rivers, streams, and lakes do not proportionally take up as much space as forests and pastures at the scale used in my study, their importance may have been underestimated. Future studies might focus on calculating distance from each bat call location to the nearest water source to determine if that particular water source is potentially being utilized by foraging bats.

It is important to consider that mobile transects create a bias in that routes can only be located along roads within a landscape. In this area of Oklahoma, pastures and cropland typically have wooded buffers that can act as corridors for foraging bats. While corridors are important, they may give the false impression that bats are utilizing the open fields because the fields make up the majority of the available habitat. To address this potential bias, acoustic surveys could be conducted by selecting sites at random distances from the road to provide a more general sense of the landscape than what is found solely along the road.

Lastly, the connectivity of the landscape should also be considered in these types of analyses. For instance, continuous pasture fields may have a different impact on bat abundance compared to a pasture of similar size that is broken up by forested corridors. The density of the corridors may even impact the amount a bat will utilize that particular habitat (Klingbeil and Willig 2009). It is important to also note that bat responses to landscape configuration like patches and corridors are often scale-dependent, so using a multi-scale approach is just as essential as analyzing the quality or quantity of habitat (Klingbeil and Willig 2009).

Although this study does not explain the direct effects of habitats like developed areas on bat abundance, it does suggest which habitats are most essential for their survival. Given the importance of forested habitat, successful management for the conservation and preservation of common and endangered bat species should focus on forested habitat. The data on species diversity can also provide valuable information in quantifying habitat requirements of individual species so that any specialized requirements of target species can be recognized.

Because WNS has not become established in Oklahoma yet, we cannot make any pre- or post-WNS population comparisons at this time. To date, there have only been 3 studies that gathered pre- and post-WNS data (Brooks 2011; Dzal et al. 2010; Ford et al.

2011). All of these studies used acoustic surveys to gather data and consistently showed that bat activity patterns changed between pre- and post-WNS years. Ford et al. (2011) concluded that long-term acoustical surveys should be made a priority, especially in areas where WNS has not yet occurred. Fortunately, Oklahoma has the opportunity to gather pre-WNS data, and we plan to continue acoustical surveys so that we can monitor population trends and watch for any changes that may occur should WNS infect Oklahoma bat populations.

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Table 1.—List of bat species for counties in study area based on the Oklahoma State University Collection of Vertebrates (COV) and Mammal Networked Information System (MaNIS).

Species	OK County (from north to south)				
	Ottawa	Delaware	Adair	Cherokee	Sequoyah
Corynorhinus townsendii (Townsend's big-eared bat)			X		
Eptesicus fuscus (Big brown bat)		X	X		
Lasiurus borealis (Eastern red bat)	X	X	X	X	X
Myotis grisescens (Gray bat)	X	X	X	X	
Myotis septentrionalis (Northern long-eared bat)		X	X		
Myotis velifer (Cave bat)	X				
Nycticeius humeralis (Evening bat)			X	X	X
Perimyotis subflavus (Tri-colored bat)	X	X	X	X	X

Table 2.—Bat species previously documented in the 5 counties represented in this study along with their preferred food and foraging habitats (Williams et al. 2002).

Species	Preferred Food	Preferred Foraging Habitat
Perimyotis subflavus (Tri-colored bat)	Moths, beetles, mosquitoes, midges, true bugs, and ants	Streams, ponds, pastures, and along forest edges
Lasiurus borealis (Eastern red bat)	Moths, true bugs, beetles, crickets, and flies	Among trees in clearings, over water, around streetlights in suburbs
Myotis grisescens (Gray bat)	Moths, beetles, flies, and mayflies	Rivers, lakes, and forest canopies
Myotis velifer (Cave bat)	Small moths and beetles	Deserts, floodplains, water, and streetlights
Eptesicus fuscus (Big brown bat)	Beetles, ants, flies, leafhoppers, mayflies, stoneflies, and agricultural pests (cucumber beetles and scarab beetles)	Cleared meadows, water bodies, trees in pastures, along streets, and above traffic
Myotis septentrionalis (Northern long-eared bat)	Moths, beetles, caddisflies, and true bugs	Forest canopies, over water, along paths or roads, and along forest edges
Nycticeius humeralis (Evening bat)	Beetles, moths, flies, winged ants, leafhoppers, and corn rootworms	Clearings, ponds, and wooded areas
Corynorhinus townsendii (Townsend's big-eared bat)	Moths, lacewings, dung beetles, flies, and sawflies	Forested and open areas over water

TABLE 3.—Percentage of each habitat type for each route along with percentage of bat calls collected in each corresponding habitat at buffers of 1 km and 2 km.

Route	Habitat	1km	% Bats	2km	% Bats
Cookson	Forest	61.9%	87.8%	69.5%	81.3%
Cookson	Agriculture	31.1%	11.7%	24.4%	18.5%
Cookson	Developed	6.1%	0.5%	5.4%	0.0%
Cookson	Water	0.8%	0.0%	0.8%	0.2%
Grand Lake	Forest	34.9%	34.3%	36.3%	34.3%
Grand Lake	Agriculture	54.8%	48.5%	52.6%	47.5%
Grand Lake	Developed	5.4%	1.0%	5.2%	2.0%
Grand Lake	Water	4.8%	16.2%	5.9%	16.2%
January-Stansbury	Forest	56.5%	69.1%	60.2%	73.5%
January-Stansbury	Agriculture	33.4%	27.6%	32.2%	24.4%
January-Stansbury	Developed	8.6%	0.5%	6.2%	0.0%
January-Stansbury	Water	1.5%	2.8%	1.4%	2.1%
Nickel Preserve	Forest	86.2%	71.7%	77.2%	76.9%
Nickel Preserve	Agriculture	4.2%	28.3%	16.1%	23.1%
Nickel Preserve	Developed	4.6%	0.0%	3.7%	0.0%
Nickel Preserve	Water	5.0%	0.0%	3.0%	0.0%
Sally Bull Hollow	Forest	69.6%	87.3%	72.0%	85.4%
Sally Bull Hollow	Agriculture	24.6%	12.7%	23.2%	14.6%
Sally Bull Hollow	Developed	5.8%	0.0%	4.7%	0.0%
Sally Bull Hollow	Water	0.1%	0.0%	0.1%	0.0%
Tar Creek	Forest	18.1%	38.3%	17.3%	43.3%

Tar Creek	Agriculture	64.7%	50.0%	65.3%	48.3%
Tar Creek	Developed	14.4%	11.7%	14.7%	8.3%
Tar Creek	Water	2.9%	0.0%	2.8%	0.0%

TABLE 4.—Percentage of bat calls collected for all 3 years for each route and combined total percentage of each species. Total number of calls recorded on each routes. Simpson's Diversity Index for bat species on each route.

Species	Route						Total
	Cookson	Grand Lake	January-Stansbury	Nickel Preserve	Sally Bull Hollow	Tar Creek	
Perimyotis subflavus	47.5%	59.6%	52.9%	43.9%	66.9%	66.7%	52.7%
Lasiurus borealis	20.9%	13.1%	14.7%	23.1%	11.5%	18.3%	17.7%
Myotis grisescens	5.1%	3.0%	17.6%	1.2%	2.2%	1.7%	6.6%
Lasiurus cinereus	1.6%	1.0%	0.2%	0.2%	0.0%	1.7%	0.7%
Eptesicus fuscus	0.6%	0.0%	1.6%	0.5%	0.3%	0.0%	0.7%
Myotis septentrionalis	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%	0.1%
Nycticeius humeralis	16.0%	21.2%	7.1%	22.3%	12.1%	8.3%	14.6%
Corynorhinus townsendii	0.0%	0.0%	0.4%	0.0%	0.0%	0.0%	0.1%
Myotis lucifugus	2.2%	2.0%	2.0%	3.2%	1.9%	0.0%	2.2%
Lasionycteris noctivagans	2.0%	0.0%	0.4%	1.5%	0.9%	0.0%	1.2%
Unknown	4.1%	0.0%	2.9%	4.0%	4.0%	3.3%	3.5%
Total Number of Bats	493	99	448	403	323	60	1,826
Simpson's Diversity Index	0.694	0.587	0.647	0.703	0.520	0.22	

Table 5.—Percentage of bat calls collected for all routes for 3 years for each habitat type and buffer size. Total number of calls recorded for each habitat and buffer size. Simpson's Diversity Index for bat species in each habitat type.

Species	Habitat							
	Forest 1 km	Forest 2 km	Agriculture 1 km	Agriculture 2 km	Developed 1 km	Developed 2 km	Water 1 km	Water 2 km
Perimyotis subflavus	51.3%	51.8%	58.4%	58.1%	58.3%	42.9%	85.7%	73.1%
Lasiurus borealis	17.5%	17.6%	17.8%	17.4%	33.3%	42.9%	3.6%	3.8%
Myotis grisescens	8.1%	7.6%	1.2%	2.7%	0.0%	0.0%	7.1%	7.7%
Lasiurus cinereus	0.6%	0.6%	0.7%	0.7%	0.0%	0.0%	0.0%	0.0%
Eptesicus fuscus	0.5%	0.5%	0.7%	0.5%	0.0%	0.0%	0.0%	0.0%
Myotis septentrionalis	0.1%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%
Nycticeius humeralis	14.5%	14.6%	16.3%	15.6%	8.3%	0.0%	3.6%	11.5%
Corynorhinus townsendii	0.2%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Myotis lucifugus	2.4%	2.3%	1.7%	1.5%	0.0%	14.3%	0.0%	0.0%
Lasionycteris noctivagans	1.5%	1.4%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%
Unknown	3.4%	3.3%	3.0%	3.0%	0.0%	0.0%	0.0%	3.8%
Total Number of Bats	1,382	1,390	404	403	12	7	28	26
Simpson's Diversity Index	0.679		0.600		0.591		0.267	

TABLE 6.—Average monthly temperatures (°C) for northeastern Oklahoma (mesonet.org).

Year	May	June	July	August	September	October
30-Year Normal	19.8	24.3	27.1	26.8	22.0	15.7
2010	20.1	26.9	27.9	28.8	23.4	16.6
2011	19.3	27.7	31.3	30.0	20.4	16.0
2012	22.5	25.6	30.3	27.2	23.4	14.8

TABLE 7.—Rainfall in centimeters per month for northeastern Oklahoma (mesonet.org).

Year	May	June	July	August	September	October
30-Year Normal	14.4	13.2	8.8	8.2	13.5	10.9
2010	15.2	12.4	7.6	3.5	14.6	5.0
2011	17.4	3.9	1.5	8.2	7.5	7.2
2012	2.8	10.7	1.9	7.2	10.3	6.9

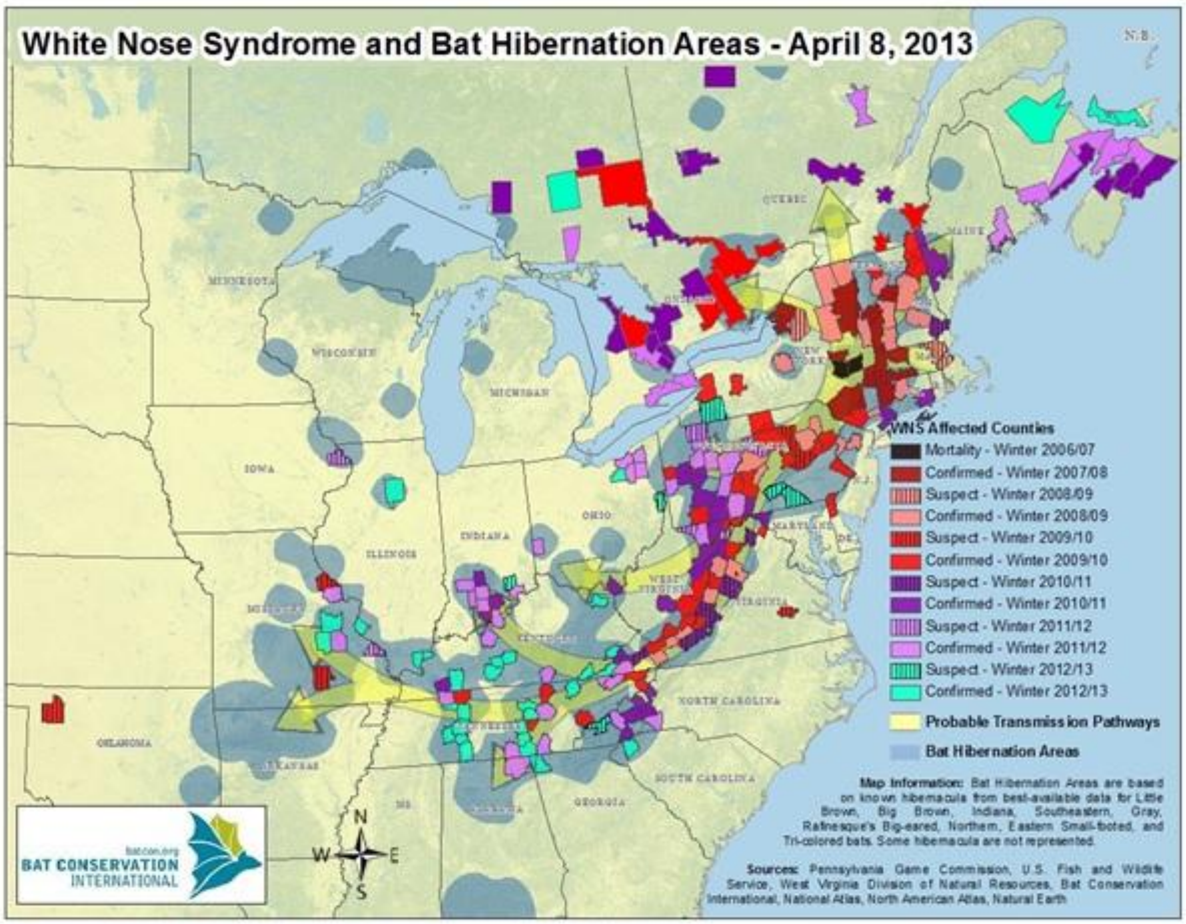

FIG. 1. –Map of confirmed and suspected WNS cases in the United States and Canada (BCI 2013).

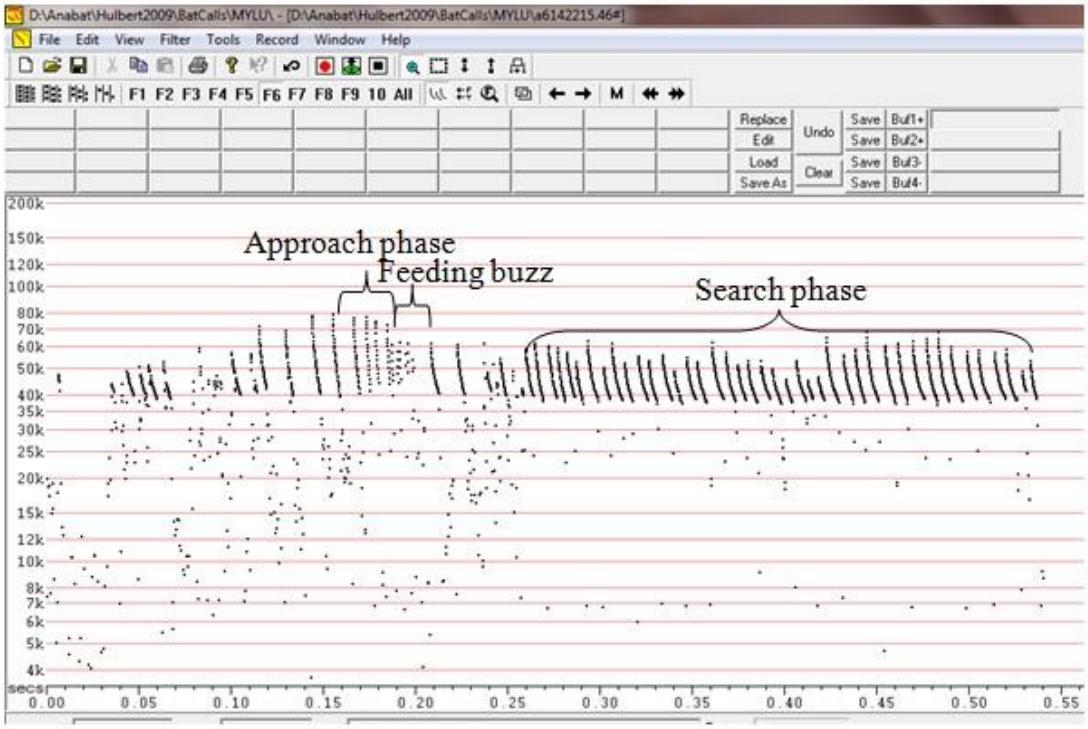

FIG. 2.—Call sequence for *Myotis lucifugus* showing the approach phase, feeding buzz, and search phase parts of the call using Analook software (Titley Electronics, Balina, NSW, Australia).

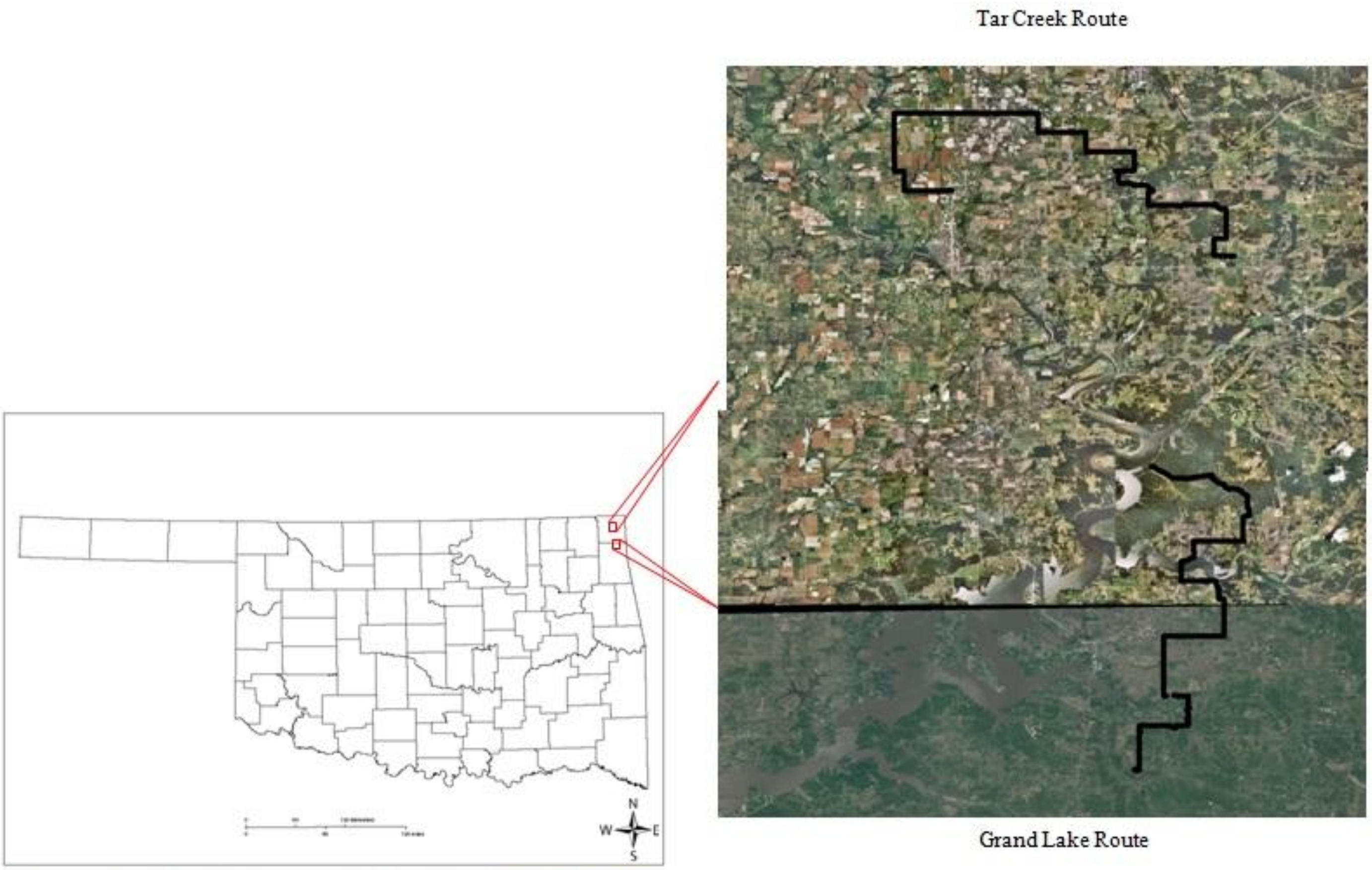

FIG. 3.—Map of Tar Creek and Grand Lake routes (yellowmaps.com).

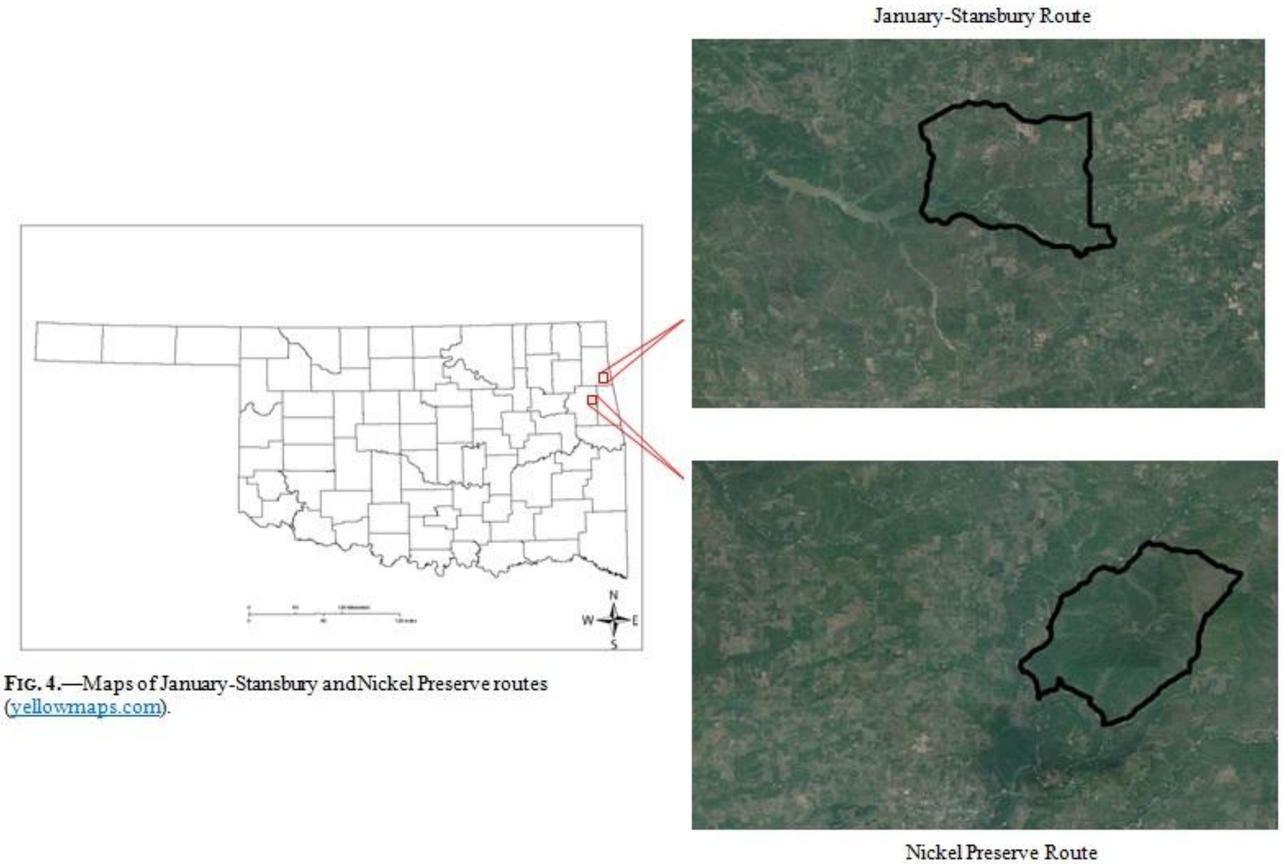

FIG. 4.—Maps of January-Stansbury and Nickel Preserve routes (yellowmaps.com).

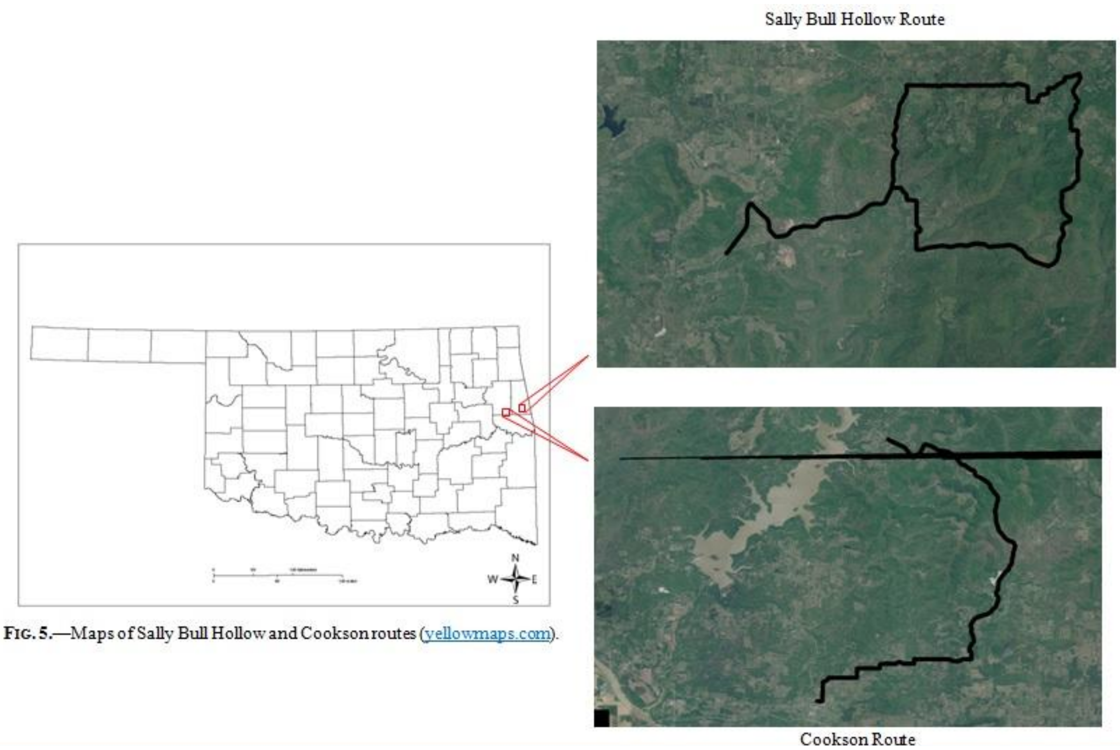

FIG. 5.—Maps of Sally Bull Hollow and Cookson routes (yellowmaps.com).

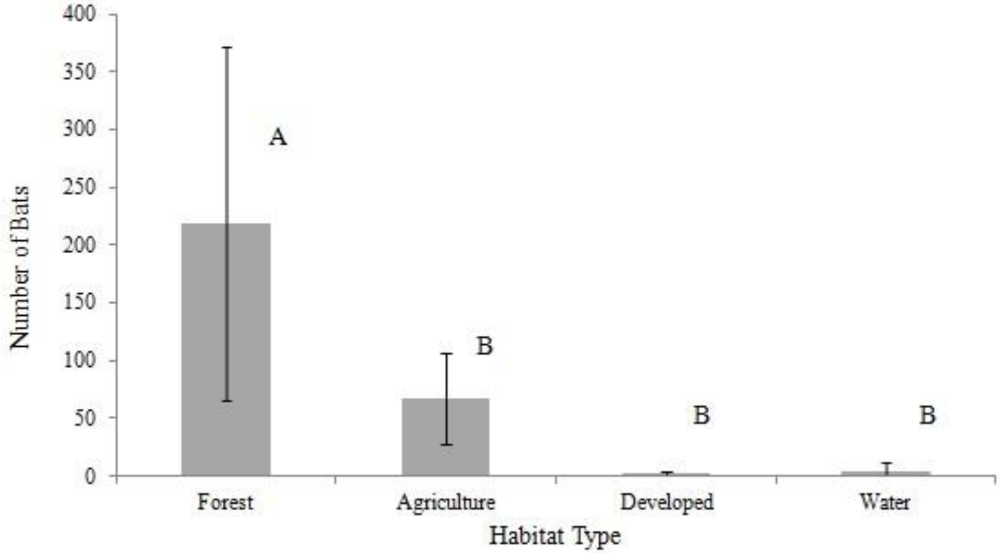

FIG 6.—The mean number of bats over all years (+ SD) in each habitat type using the 1 km buffer, shared letters indicate no significant difference in GLM.

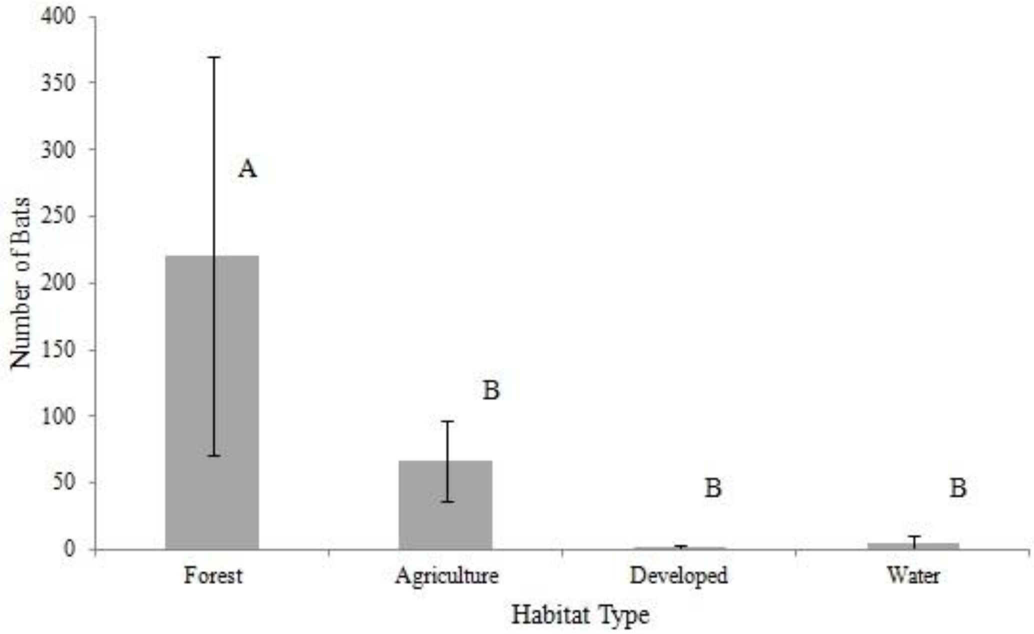

FIG. 7.—The mean number of bats over all years (± SD) in each habitat type using the 2 km buffer, shared letters indicate no significant difference in GLM.

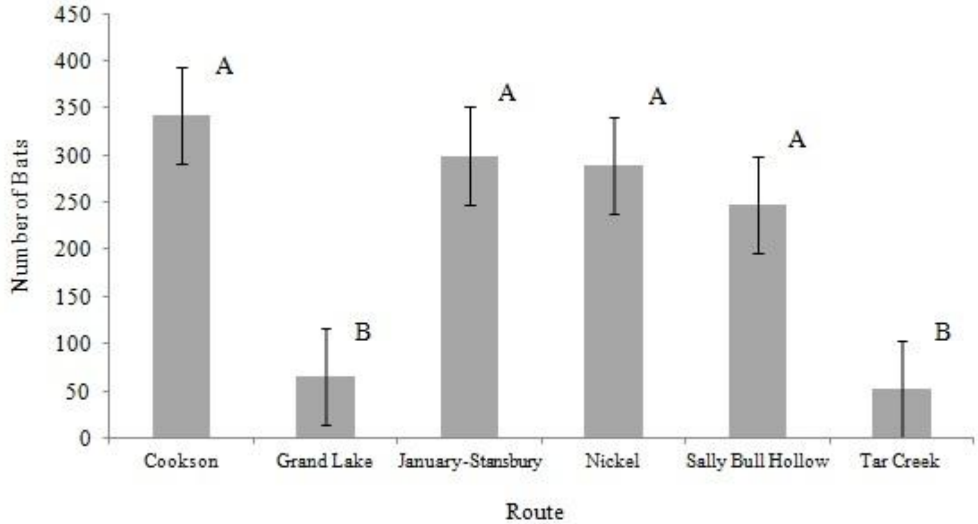

FIG. 8.—The mean number of bats (± SD) for each route, shared letters indicate no significant difference in GLM.

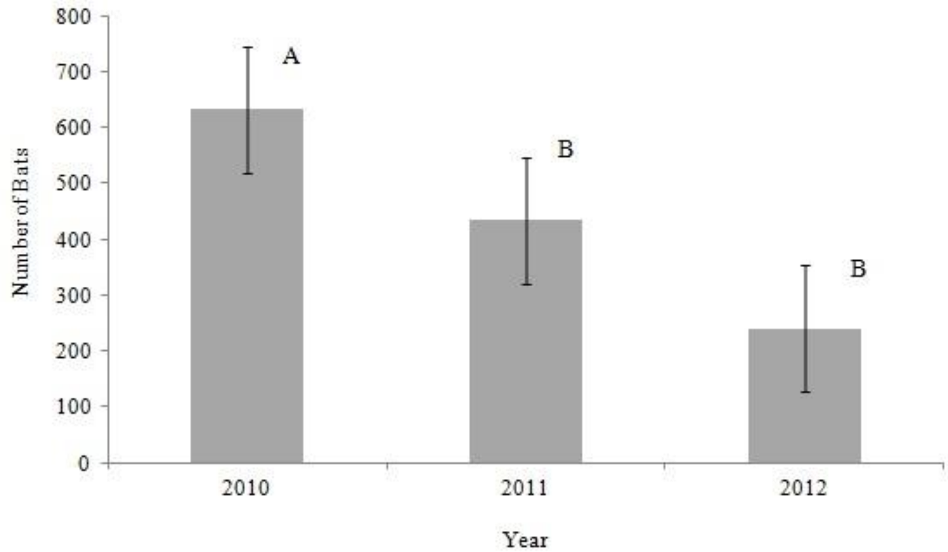

FIG. 9.—The mean number of bats for each year (± SD), shared letters indicate no significant difference in GLM.

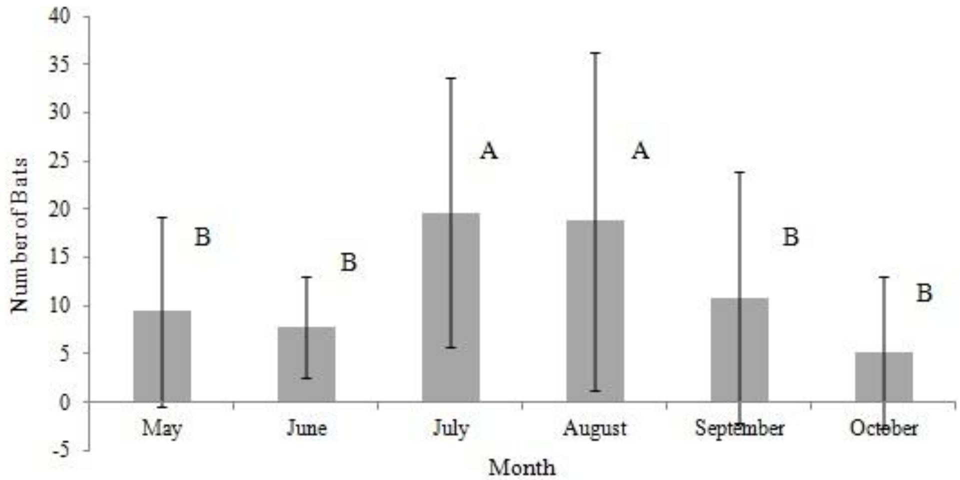

FIG. 10.—The mean number of bats (± SD) for each month for all routes over 3 years, shared letters indicate no significant difference in GLM.

VITA

Andrea Lynn Korman

Candidate for the Degree of

Master of Science

Thesis: TYPE FULL TITLE HERE IN ALL CAPS

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Biographical:

Education:

Completed the requirements for the Master of Science in Zoology at Oklahoma State University, Stillwater, Oklahoma in May 2013.

Completed the requirements for the Bachelor of Science in Biology and Environmental Science at Dickinson College, Carlisle, Pennsylvania in May 2009.

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