IMPLEMENTING THE NORTH AMERICAN BAT MONITORING PROGRAM IN NEBRASKA: AN ASSESSMENT OF NEBRASKA BATS WITH AN EMPHASIS ON CITIZEN SCIENCE

By

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Over the past decade bat species in North America have been under immense stress due to anthropogenic activities throughout the continent along with severe declines from foreign invaders. Though many specific anthropogenic related activities such as deforestation, land-use alteration, and hibernacula disturbance/modification were the primary culprits of negative impacts on bat species in the past, they pale in comparison to the threats bats face today. White nose syndrome a disease caused by the fungus *Pseudogymnoascus destructans* and wind energy development have caused declines and disruptions to the bat populations of North America at an unprecedented rate.

Due to the significant contribution to insect population control that bats exhibit throughout the continent they are considered to be a major benefit to both ecosystems and agricultural industries. Though they are known to provide significant services to ecosystems large information gaps exist in what physical properties influence their presence on the landscape. Especially in states like Nebraska where the large extent of agricultural and grassland ecosystems has made their study difficult in the past. In order to address these information gaps we implemented the North American Bat Monitoring Program throughout Nebraska in order to answer baseline questions about bat habitat use and ensure that monitoring efforts continued into the future and benefit bat research throughout the continent.

Dedication

For those who have ever doubted themselves, the path they have chosen, or the people they ended up with. As a great man once said “not all those who wander are lost” - J. R. R. Tolkien. Keep wandering and know that you matter in this world.

Acknowledgments

I want to take a moment to acknowledge all the wonderful people that I have had the honor to share this journey with. I have been a positive person for most of my life, however, the years working on this project have tested me both in my professional and personal life. I would not be the man I am today if it were not for the inspiration, support, knowledge, compassion, laughter, and love of my family and the people I have met along this path.

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INTRODUCTION

Bat species throughout the world have had an interesting relationship with humanity over the millennia. At times the relationship can be tumultuous and even volatile and in other times humanity appears to be in awe or reverence of the abilities of these incredibly diverse mammals. Some ancient societies have perceived bats as gods or deities in the past (Frembgen 2006) however, common folklore and the fear of the unknown has created ghoulish characters represented by bats in popular literature and media sources which have led to animosity or misperceptions of them (Sexton and Stewart 2007, Rego et al. 2015, Musila et al. 2018). Only in the past century have scientists uncovered the remarkable physiological and social characteristics of bats including their agile flight capabilities, their use of echolocation to find food and navigate in almost complete darkness, along with their complex social communication and structures (Hutson et al. 2001, Kunz et al. 2011). Regardless of our perceptions of bats they provide critical ecosystem services throughout the world that largely benefit the ecosystems they inhabit (Hutson et al. 2001, Kunz et al. 2011). Whether bats are pollinating flowers, dispersing seeds, predating vertebrates, or controlling non-vertebrate species populations bats have a significant ecological impact on the world (Hutson et al. 2001, Kunz et al. 2011). The bats within the state of Nebraska (NE) are no exception to this theme.

The 11 species of bat commonly found in Nebraska are all insectivores and consume massive quantities of insects throughout the diverse ecosystems of Nebraska. Estimates of their economic contribution to agricultural systems globally are approximately over 3.7 billion dollars annually, so conserving their populations is likely beneficial not only to humans but the ecosystems they inhabit (Boyles et al. 2011, Maine and Boyles 2015). However, like many wildlife species in our increasingly anthropogenically influenced world, bats have suffered disturbance and habitat loss throughout the past century (Racey and Entwistle 2003, Weller et al. 2009). This disruption to their populations has occurred at an unprecedented level in the past two decades in North America with the emergence of two new threats, wind energy development and the disease white-nose syndrome (Blehert et al. 2009, Frick et al. 2010, Foley et al. 2011, Blehert 2012).

Wind energy development has increased in the past several decades and causes high levels of mortality in migratory and tree roosting bats like the silver haired bat (*Lasionycteris noctivagans*), eastern red bat *(Lasiurus borealis*), and hoary bat (*Lasiurus cinereus*) which are all common in Nebraska (Arnett et al. 2008, Arnett and Baerwald 2013, Hein and Schirmacher 2016). Some estimates have determined that 3-4 bats are killed at each wind turbine each year, which when extrapolated to the number of turbines in the country is a mortality rate that could have significant population impacts over time (Arnett et al. 2008, Hein and Schirmacher 2016). Unfortunately, unlike cave or building hibernating species that congregate in high concentrations in locations that have been monitored for decades, giving us relatively reliable population estimates, many of the migratory species are understudied and researchers have little to no idea whether wind energy is impacting their populations (Kunz et al. 2007).

White-nose syndrome (WNS), a disease caused by the fungus *Pseudogymnoascus destructans*, has caused catastrophic decline of cave and building hibernating bats since

2006 in the eastern portion of the U.S. (Frick et al. 2010). Since it was discovered in New York State the disease has spread across the United States and produced >70% mortality in a majority of the hibernacula that have been infected, with some species reaching 99% mortality (Frick et al. 2010, Fisher et al. 2012). These challenges mean that largescale efforts that cross state boundaries need to be implemented in order to conserve bat habitat and influence their recovery or we may be facing an extinction event in North America with potentially significant ecological and agricultural ramifications (Coleman et al. 2011). Though there are a limited number of publications researching Nebraska bats, and landowners throughout the state are commonly surprised to discover that there are bats utilizing their property for food, bats reside in every corner of the state in a large range of abundances. The unique placement of Nebraska at the center of the country has produced a transitionary zone between the East and the West where several species are at the fringe of their range on either side of the state. With several wind turbine facilities established in the state in recent years and the enormous wind energy potential in several portions of the state Nebraska migratory species of bats will likely continue to be impacted by wind turbine related fatalities. This in combination with the discovery of WNS in Nebraska, (confirmed in 2015) (Fritz and Hibbard 2015), indicates that now is a critical time for Nebraska and University resources to be directed at quickly and effectively establishing conservation goals to protect bats and mitigate future negative impacts.

Within Nebraska a handful of researchers have been working diligently over the past several decades to increase knowledge pertaining to hibernacula locations, life history, diet, activity patterns, distribution, and reproductive timing of Nebraska bats using primarily mist netting techniques (Benedict et al. 2000, Benedict 2004, K. Geluso et al. 2004, Geluso et al. 2005, 2008, 2013, 2015, Damm and Geluso 2008). However, given the limitations of mist netting in prairie and agricultural landscapes which dominate a large portion of Nebraska large information gaps exist in the understanding of bat distribution, habitat preferences, and populations in the diverse ecosystems represented in Nebraska. With only a limited number of publications on bats' usage of prairie ecosystems in the United States, knowledge is significantly lacking. With the incredible advances in ultrasound acoustic bat detection and echolocation call analysis software over the past few decades we are now at a point in time when all bat populations can be documented and studied, not just those found in corridors that can be sampled using mist nets. Using these new technologies, our mission was to establish a monitoring program within Nebraska that allows us to fill in information gaps, contributing to the knowledge of how the bat species of the plains are utilizing the Nebraska landscape and their relative abundance. With an emphasis on long-term monitoring, compatibility with citizen scientist involvement, and the ability to contribute to a national database I turned to the North American Bat Monitoring Program (NABat) in order to achieve these goals as efficiently and effectively as possible.

THE NORTH AMERICAN BAT MONITORING PROGRAM

The North American Bat Monitoring Program (NABat), which was finalized in 2015, is a revolutionary new approach to answering bat specific research questions across entire ranges of North American bat species (Loeb et al. 2015). Though a significant amount of research has been conducted in (at times) isolated locations or across only portions of species ranges, the developers of NABat had the goal of expanding bat research to encompass the entire North American Continent with one consistent framework. With the end goal of conserving bat populations and the ecosystem services they provide. The program combines several acoustic sampling techniques in order to establish long-term monitoring that can be tailored to fit a state's needs while also allowing research to contribute to a national database (Loeb et al. 2015). The flexibility of the program in sampling design and site selection made it seamlessly integrate with the needs of Nebraska while simultaneously being useful to the continental efforts. Through acoustic based sampling we have been able to collect vast amounts of data on Nebraska bats without the limitations of mist netting or sampling/site selection constraints that do not directly benefit Nebraska. Another key component of NABat that directly influenced a Nebraska based program is the seamless integration of Citizen Science data collection into the program that allowed us to increase public awareness of the importance of Nebraska bats and allow for direct participation from the public in bat research.

Through the flexibility and relatively simple structure of NABat we were able to develop the Nebraska NABat program with an emphasis on Citizen Science data collection. Due to the sometimes cost prohibitive aspects of large-scale research projects it can be difficult to establish large datasets that fully encompass a state's needs and are not abandoned due to a lack of funding or resources. Many success stories of the past including the Breeding Bird Survey, National Bat Monitoring Programme, and North American Amphibian Monitoring Program, heavily influenced our utilization of Citizen Science to carry out a portion of our data collection (Schmeller et al. 2009, Barlow et al. 2015, Kosmala et al. 2016). Though there have been many critiques of data collected by Citizen Scientists in the past (Kosmala et al. 2016), reductions to cost and the benefits to public awareness and involvement in wildlife research that help conservation throughout a society outweighed our concerns (Forrester et al. 2017). This project followed the philosophy that even technicians can perform research poorly if not given the correct attention and training. With careful attention to the limitations of specific volunteers, detailed training, comprehensive/easy to follow manuals and a program coordinator that is on-call for help. This coupled with the majority of expertise required in bat acoustic ultrasound research occurring in the data analysis and site selection portions of most bat acoustic research projects, portions that my volunteers are not interacting with, put any hesitation about volunteer involvement to rest. Throughout the two years of sampling for this project, we were able to maintain scientific rigor and include a wide range of Citizen Scientists from a diverse set of backgrounds.

Here I illustrate the process used over two years of sampling and data analysis to develop the program, establish long lasting relationships with landowners, recruit volunteers, and prepare for the future of NABat. I am hopeful that through documenting my process and displaying what I learned and achieved that this document can provide insight and be a tool for other states interested in implementing the NABat program.

METHODS

NORTH AMERICAN BAT MONITORING PROGRAM

The core of the Nebraska NABat program followed the methodology outline in Loeb et al. (2015). NABat utilizes 10 km x 10 km grid cells that were first developed by the USDA Forest Service for a monitoring program in the Pacific Northwest (Ormsbee et al. 2006, Hayes et al. 2009, Rodhouse et al. 2012). The grid was extrapolated across North America in order to establish a master sample (Larsen et al. 2008, Loeb et al.

2015). These 100 km^2 grids are considered a sufficient size for modeling and mapping bat species distributions (Rodhouse et al. 2012). In order to account for spatial balance across the continent the NABat team assigned values to each grid using the generalized random-tessellation stratified (GRTS) survey design algorithm (Stevens and Olsen 2004). Subsamples of the master sample can then be specified based on a distinct geographic location, which for my purposes was the state of Nebraska (Figure 1.1). This methodology ensures randomization and spatial balance by selecting the lowest GRTS values within an area. GRTS allows for grid cell addition and subtraction as monetary resources, landowner permission, or other unforeseen changes occur over the course of a long-term monitoring project. Using the master sample, I selected the 50 grid cells with the lowest GRTS value with an end goal of at least 30 established cells after the first year of sampling.

Within each grid cell two methodologies monitor bat species over the entire 10 km x 10 km area. The first involved 2-4 stationary acoustic detectors, deployed for at least 4 nights in each grid cell during June and July each year in order to sample the resident population during the maternity season. The NABat protocol places an emphasis on placing detectors in diverse locations to ensure they capture all the bat diversity within the grid cell. While these stationary detectors allowed us to determine habitat variables that are associated with presence, they do not allow us to determine the populations of bats or determine if a decline is occurring. In order to estimate relative bat abundance trends and the differences across the state since abundance differs geographically, the NABat protocol also uses mobile transects within each cell.

While stationary detectors allow us to make inferences about activity patterns and use this information as clues to abundance there is debate within the bat research community about the use of activity as an approximation of abundance. This debate is largely driven by the high level of spatial and temporal variation in bat activity levels, since they will routinely adjust their foraging locations in response to unknown or difficult variables to account for (Hayes 1997, Ciechanowski et al. 2007). For example, a stationary detector could have 1000 recordings of a specific species at a single location, however, we are unable to distinguish individuals. Therefore, that could be 1000 individual bats passing a detector or 1 bat circling a detector 1000 times over the course of a night. Mobile transects address these problems. By attaching an ultrasound microphone on the roof of a vehicle and driving 32 kph along a predetermined route, which is faster than the 9-32 kph that a majority of bats can fly (Hayward and Davis 1964, Patterson and Hardin 1969), we can assume that each bat recorded is a unique individual. These predetermined routes consist of a 25-45 km length of continuous road that does not double over any road driven previously in the same transect. Each 10 km x 10 km grid cell contains one transect that is driven twice each year between June and July (Loeb et al. 2015). Transects are sampled within a week of one another and are completed on two days with similar conditions of temperature, no precipitation, and wind conditions. The transects are established with the goal of crossing and neighboring all of the habitat types found within the cell.

The tested, supported, and comprehensive design of NABat was deemed as a natural fit for answering the large-scale questions Nebraska land managers and wildlife researchers were interested in answering. With some minor modifications to the stationary detector site selection methodology and an integration of surveying techniques that support citizen science, discussed in detail below, I was able to begin implementing NABat in Nebraska in 2016.

Year 1 – Pilot Year

In accordance with the objectives of the Nebraska Game and Parks Commission, NE NABat was established with an emphasis on long term monitoring and citizen science involvement. This made the first year especially critical in setting a strong base to ensure that future years were successful. A primary concern for this project involved access to sites. Nebraska is 97.2% privately owned which means that success was dependent on access from a network of more than a hundred private landowners to ensure sampling was wide spread and encompassed the entire state (U.S. Bureau of the Census 1991). This meant that we had to put a large amount of effort in establishing trust with the landowners we were planning to work with into the future. Sites would also be re-visited by volunteers in the future which meant that thoughtful site selection was a necessity the first year to ensure that sites were easily accessible by the general public, represented the targeted habitat in the cell, were good locations to successfully record bat echolocation sequences, and would be able to be re-visited each year. Another key feature of each cell that had to be established were reliable transect routes that were safe to drive at 32 kph, reliable during the wet parts of the summer, and crossed all the dominant habitats found in the cell.

Equipment

For Nebraska NABat I used 16 Anabat Express (Titley Scientific) zero crossing bat detectors for stationary deployments. Using a simple bracket developed by my colleagues Michael Whitby and Zachary Warren, detectors were attached to an extendable 1.8-3.6 m painter's pole (Figure 1.2). Although this is a shorter pole than many studies use, the short overall length made transporting poles by volunteers much easier along with widening the range of vehicles that volunteers could have. Anabat Express units were selected because they are easy to setup, have a battery life of 8-10 days, and reduce storage needs because they record zero crossing files. For driving transect data collection 4 Anabat Walkabouts with an extension cable and a suction cup mounted microphone were used. These devices record in full spectrum and have a real time display that shows when bats are being recorded. The display added to the enjoyment of volunteers that were driving transects and allowed for better quality control if an issue occurred during sampling (i.e. program crashing or cable detachment). With this many detectors I was able to establish 4 NE NABat kits making equipment easily transferrable from one volunteer to another in the future.

Modifying NABat for Nebraska

In Nebraska we are very fortunate that a majority of the state is covered with small roads that boarder agricultural fields and produce a grid like structure. This grid structure is especially beneficial for establishing bat driving transects. This is not the case in many states especially further to the west. Many states that have been implementing NABat have focused on the stationary points of the grid cells while putting less emphasis on driving transects because of a lack of roads or a lack of human resources to drive them. With the grid system of roads and a volunteer base in mind I made it a priority that a grid cell would not be selected for the Nebraska NABat program unless it had adequate roads to safely complete a driving transect. This resulted in some cells especially within the sand hills portion of the state being dropped due to only minimum maintenance roads being available.

To capture all the bat diversity within each grid cell while also including spatial balance and randomization I applied the GRTS survey design algorithm to land cover classifications. Using the USGS 2011 National Land Cover Database I simplified their land classifications into groups that reflected the 9 dominant land cover types in Nebraska where detectors could be effectively placed (Table 1.1) (U.S. Geological Survey 2014). By calculating the area of each of these land classification groups I was able to determine which four were dominant (by area) in the grid cell. Each of the four dominant land cover classifications of a cell are then sampled using a single stationary detector. If a cell contained only three different classifications, then the highest classification by area received a second detector. If the cell contained only two classifications, then each classification received two detectors. No cells had less than two land cover classifications. In order to reduce the amount of selection bias that could be influenced by landowners that are easy to contact, perceived excellent bat habitat, or proximity to one another I utilized the same GRTS survey design algorithm used for the larger NABat 10 km by 10 km grid selection (Stevens and Olsen 2004). Through combining the areas under the same classification and assigning GRTS points within the polygons I was able to use the same number ranking system to accept or reject sites based on their proximity to the road, landowner permission, and verification that the land classification matched on the ground observations. This created an ideal random sampling structure that added organization and a systematic approach to cycling through dozens of landowners.

In order to prepare the program for citizen scientists all the data collection at the site level had an emphasis on efficiency and reducing complexity. The general rule was that sampling procedures should be simple enough to teach to anyone in the span of a day. This allowed for general site characteristics without bogging down future volunteers with intensive data collection that could deter future involvement or increase the risk of volunteers not recording certain values. Using strategies such as binning values into easily estimated groups served my purposes and created a quick protocol that anyone could carry out. Through testing the data collection process in the first year I was able to adjust and fine tune the protocol and the data collection sheets.

Establishing Landowner Relationships

Because private landowners are an integral component to the Nebraska NABat program, a large portion of time and energy was dedicated to creating good relationships with them and providing them with information regarding the program. Previous members of the Nebraska Fish and Wildlife Cooperative Research unit had experienced extremely low success rates with cold calling landowners to ask for permission. With this knowledge of the Nebraska environment I decided to pursue face to face interactions with landowners. My technicians and I approached landowners as excited bat researchers from the university that were eager to research their property and discover what bats were there. We placed an emphasis on selling our passion as students of ecology eager to help the bats of Nebraska.

My technicians were also trained in a series of procedures and principles on how to approach and interact with landowners. I provided my technicians with a series of quick facts that were easy for landowners to relate to, show the importance of the work we were doing, and pique their interest in what bats were utilizing their property. These facts included the importance of bats to agricultural ecosystems due to their predation on insects, how many species could be found in the state, how the detectors we are deploying work, information about white nose syndrome and the current threats facing bats. In order to avoid the appearance of a salesman or person of authority my team members wore School of Natural Resources at University of Lincoln Nebraska hats and I instructed them to not carry clip boards or other documents in their hands as they approached doors. Any materials needed after making a first impression could be removed from the work vehicle later. My technicians were instructed to not appear as authoritative scientists but instead as excited students.

Upon arrival at a landowners house we provided them with a letter briefly discussing the project and providing my contact information. Business cards from the University with my contact information were also provided. Detailed maps of the site we were planning on sampling were also provided with roads clearly marked to give them an idea of where a detector would be. This was a time to discuss their preference on where a detector would go. Since I was planning on establishing a long term relationship with each landowner I wanted them to have some say in where the detector went within reason. This allowed us to find a good access point, avoid cows in pastures, and put the landowner at ease with where we would be on their property. Once we had established contact and confirmed that they were interested in sampling on their property I had each landowner provide an address for them to receive results from our survey and a preferred phone number for us to speak with them in the future or alert them to any issues we had (e.g., cows escaped, down fences, hazards they may want to know about). My crew was instructed to treat their property with extreme respect by being very careful to close gates if they were used, avoid stepping on crops, etc. I did not want a small mistake to prevent a future relationship with a landowner or their neighbors.

Grid Cell Establishment

When establishing a site for a stationary deployment we used a buffer system around the random points in order to pick the best recording spot available. Within a 200-meter buffer around the random point we selected the best open recording environment in order to obtain good clear echolocation calls. The point was also placed in a spot that reflected the land classification type that it was assigned to. For example, if a point was supposed to be in upland forest but the random point placed the surveyor in an open field next to a forest the point was shifted so that it was within an upland forest. This was necessary due to general amount of error found in the NLCD layer. The next step was to attempt to locate a feature or vegetative structure that would be likely to harbor the highest abundance of bats. Once a site was selected GPS points were taken, site maps drawn, and photos were taken in each direction. This would make finding the exact location easier in the future for volunteers.

Driving transects were assessed to ensure that they were safe and reliable. With the help of aerial photography and NLCD land cover layers a route was selected for each grid cell (U.S. Geological Survey 2014). Transects maps were established in base camp and transferred to hand held GPS units to provide turn by turn directions throughout the route (Garmin BaseCamp Version 4.7.0). Transects were tested by technicians and myself during daylight hours in order to verify drivability. It was very common in the first year for a grid cells transect to require revision due to minimum maintenance roads, high volumes of cars on 50 mph roads, and bridges that were no longer standing. Careful consideration was given to ensure that volunteers in the future would get their vehicle stuck or have an increased risk of collision due to a transect route.

Year 2 – Volunteer Year

Developing Relationships with Landowners

Since the project was so dependent on the continued support of landowners, effort was put into providing them with information about the NE NABat program and the bats of Nebraska in general after the first year. Each landowner received a packet of information which discussed in detail all of the sampling procedures and the research questions associated with NE NABat. Another portion of the packet discussed the threats facing NE bats including wind energy and white nose syndrome along with the general benefits that bats provide to Nebraskans and agricultural systems. Landowners were also given a document that gave a detailed profile for each bat species that can be found in Nebraska with a picture, common insects they consume and what their conservation status is. The final portion of the packet was a personalized letter thanking them for their support, a listing of all of the species recorded on their property the summer before, and a request to continue sampling into the future.

About 2 weeks after sending the packets to each landowner, I started calling each landowner to confirm they had received the packet. This was also the time when I discussed the future of the project, our goals to continue it for as long as possible, and if they would be willing to allow us on their property in the summer of 2017. This was a somewhat risky strategy but I wanted the first year to show landowners how non-invasive the sampling was and how they would barely realize we had been there. Calling each landowner was a highly time consuming process but it was the best course of action given the personal interaction with the public I was trying to achieve for with this program.

OBTAINING AND TRAINING VOLUNTEERS

From August 2016 through March 2017 I reached as many members of the public as possible in the form of information talks about bats in general and more specifically NE NABat. This took the form of about a dozen bat talks at colleges, high schools, and non-profit organizations. At the end of every presentation I gave a pitch to anyone interested that I was looking for volunteers willing to help with NE NABat. Through this outreach and the support of the Master Naturalist Program, a University of Nebraska Lincoln program that allows volunteers to work for research and management projects around the state in exchange for training, I established a citizen science base to conduct surveys throughout the state.

In order to ensure volunteers were serious and able to conduct the work I sent a list of requirements to each person that showed interest in the project. Volunteers had to be able to complete a full grid cell of sampling (2-4 stationary deployments and 2 driving transects), be able to drive at night, have a vehicle that can handle dirt roads, carry 20 pounds up to a mile, and be willing to take a one-day intensive training course. This strict set of requirements pushed out those that were only partially interested or had physical limitations that would have been problematic in a field based setting.

Training days were established based on simple polling to determine the best day for a group of individuals. I had three trainings in three regions of the state which made the process more convenient for volunteers. Training consisted of a two hour talk that discussed bat echolocation and the importance of bat detector placement, safety concerns, and a hands on use of all of the equipment used. This was followed by training outdoors for volunteers to practice setting up the equipment and taking site measurements. After a break for dinner I had volunteers come back for a night time mock transect so that they were able to get used to the GPS turn by turn directions and using the Anabat Walkabouts. Since an emphasis was placed on simplifying the protocol for citizen scientists these trainings were very successful and very much appreciated.

DESIGNING SAMPLING SCHEDULE AND ROTATING EQUIPMENT

One of the biggest hurdles when establishing a sampling protocol involving an entire state, volunteers, and a limited number of sampling kits, is getting the equipment into the hands of those who needed it. A logical and effective answer to this was establishment of sampling "hubs" in different portions of the state. Partnering with the Chadron Game and Parks office and the Crane Trust I established 3 "hubs" to house equipment when it was not being used by volunteers (with the third being my office). This meant that a volunteer could simply visit one of the "hub" locations and checkout the kit when they were scheduled to sample a grid cell.

In an effort to increase the effectiveness of our driving transect data I made an effort to have each grid cell be sampled within a week of the date it was sampled the previous year. This was to account for the only known variation over the course of the summer when newly volant young bats begin to forage on their own, which occurs between the beginning and middle of July each year (Benedict 2004, K. Geluso et al. 2004, K. N. Geluso et al. 2004). Bat populations are known to increase dramatically as young born that year begin to forage for themselves later in the summer. I wanted to avoid this causing artificial increases or decreases in the number of bats recorded from one year to another by maintaining similar dates each year for transects. This proved to be a beneficial restriction since I was able to set a specific set of dates that each grid cell had to be completed, making volunteer sign up much easier to schedule.

Managing Volunteers

Even with a long training day that walked through the entire protocol in detail, volunteers cannot be expected to remember each and every specific step by heart after a few weeks. Knowing this issue would most likely come up, I developed a detailed protocol to help guide volunteers. This protocol included detailed pictures and explanations to show each operation that needed to be performed from simply turning on a GPS to measuring the DBH of a tree. The protocol was very effective at illustrating all of the activities and volunteers were encouraged to read over areas they were not confident the night before.

In order to maintain as safe of an environment for volunteers as possible, I was in constant contact with them. Volunteers were instructed to either call, text, or email me when they were planning on leaving for sampling and to follow up with me once they had returned home. If any difficulties or confusion arose, volunteers were instructed to contact me night or day. However, this constant contact fostered relationships, placed them and myself at ease, and produced an overall positive experience for everyone. No volunteers, technicians, supervisors, or coordinators were harmed in the forging of this program.

RESULTS

YEAR 1 – NE NABAT ESTABLISHMENT

In 2016 with the help of 2 technicians I was able to fully establish 35 NABat grid cells in Nebraska (figure 1.3). This included 125 unique stationary detector locations sampled for between 4 and 6 nights and 35 driving transects sampled twice. In total there were 100 private landowners that allowed us onto their property in 2016. These landowners represented 122 of the total number of stationary points, with three of the 125 points being located on the Game and Parks Commission property.

The door to door method for contacting landowners received a very positive response and high rate of success. There were only 10 landowners across the state that did not allow us to sample their property. My entire crew was extremely surprised at the response to our approach and the relative ease at which we established trust with landowners when they were approached in a thoughtful and respectful manner. However, the door to door method did pose its own set of obstacles and challenges. Frequently the owner of a piece of property did not live on site and forced my crew to drive a half hour or more to track them down. The other downside was not necessarily catching the landowner at home and being forced to come back later and try again. Usually through good planning at the beginning of a work day it would be possible to create an efficient method for a specific cell but it took a few weeks to create a rhythm.

Year 2 Volunteer Involvement and Landowner Retention

In the second year of NE NABat I was able to maintain a high level of site and landowner retention. All of the 35 cells established in 2016 were sampled again and all of the transects that had been vetted and tested the previous year were driven again. Of the 125 sites from 2016, 119 of them were sampled again in 2017, with 1 more added as a replacement, bringing the total to 120 stationary sites. Of the 100 private landowners that gave us permission in 2016, 96 participated in 2017, with one being added as a replacement, bringing the total to 97 private landowners.

After establishing contact and trust with landowners in 2016 and sending them detailed information packets about the project and the bats that were discovered on their property we received a high amount of validation and support. Through personally calling each and every landowner I was able to connect with them, establish continued trust, and answer any questions they had and/or send them to website for them to explore more information about bats. Though this proved to be a cumbersome task it was very fruitful and at times extremely entertaining (many of the landowners I have the pleasure to work with are very fun and pleasant people). During this process at times I had to make several phone calls to the same landowner in hopes of catching them at a good time. The most successful call time was between 3:00pm and 6:00pm, however many landowners that did not answer during these times did answer between 9:00am and 11:00am. After attempting to contact all landowners through phone calls over 1 month, 9 were still not answering their phones or the number they had given was no longer working. To deal with this scenario a colleague and I drove a loop around the state to knock on doors and re-establish contact. This was successful for 7 of the 9 landowners.

The most prevalent reason for dropping a landowner from the project was not being able to get ahold of them. Only one of the landowners actually said no when asked for permission again. Many landowners were eager to have a discussion with me and many of the phone calls ended up being about a half-hour. During these conversations I would routinely take notes about topics we had discussed for reference the following year. The packets given to each landowner were also received very well. Many landowners were excited to share the information with their children, neighbors, and friends.

CITIZEN SCIENTISTS

In an attempt to not overwhelm myself with managing volunteers, I had planned on only about half of the cells surveyed in 2017 to be completed by volunteers. Of the 35 grid cells 13 were completed by volunteers. In total there were 12 volunteer “groups” that participated in sampling. The reason I have called them groups is because several individuals brought significant others or family members with them when they went out to survey a grid cell. This was encouraged if available for safety reasons. Most volunteers only worked two days on any given grid cell. The average amount of time spent on the first day was about 6 hours before travel time and 4 hours the second day. Most volunteers had a commute of about a half hour to the cell they surveyed but 2 participants had over an hour commute. This meant that on average a volunteer spent about 12 hours completing a single grid cell.

The data collected by volunteers was comparable to technicians that worked on the project both in 2016 and 2017. A majority of this can be attributed to the simplification of the sampling procedures that were easy to teach volunteers. Following up with volunteers after they had finished a grid cell gave me a significant amount of positive feedback. The largest obstacle while working with volunteers occurred towards the end of the season when a scheduled volunteer had forgotten specific portions of the procedures learned in May. Most of these issues were easily remedied through on the phone support provided by myself and the guided referencing of the protocol provided to each volunteer.

Cost of Sampling

The first year of sampling had the highest cost associated with it. Not only was equipment purchased the first year but also a second technician was hired in order to ensure that the highest number of grid cells possible were established. Based on the sampling designed I developed the cost of equipment was about $28,300.00 (table 1.2). Vehicle costs were also much more expensive in 2016 due to the added mileage associated with tracking down landowners (Table 1.3). Since vehicle costs are specific to the entity that is implementing a wildlife research project I have calculated our mileage and put them in the context of gas mileage and the federal mileage rate for simplification (Table 1.3). A simple break down of the costs associated with labor was also created to give an idea of the change in price over the course of the project (Table 1.4). A summarization of the total costs of labor and vehicle mileage was also created to show the change in costs over time (Table 1.5).

After the initial establishment year, we were able to cut costs through offsetting labor with volunteers and reducing mileage by not having to go door to door to landowner homes. This resulted in a savings of around $8,000, with a majority of money being saved on mileage. In the future when a technician is no longer needed to support a coordinator we will be able to further reduce cost. The projected savings from 2016 to future years is $12,300; this money can be used to update and fix damaged or malfunctioning equipment, replace aging batteries, and increase outreach opportunities.

DISCUSSION

VOLUNTEERS – PROS AND CONS

There are several pros and cons when working with a group of volunteers on a large scale research project. On the negative side, utilizing volunteers involves a wide range of skill levels and experience in working outdoors that can be difficult to manage. Although some volunteers were retired biologists that have an extensive background in natural resources, for others this was the first time they have worked on a research project in a field based setting. After receiving a high amount of interest in the project and a lot of emails of potential participants, it became clear that I had to set a strict list of requirements to weed people out. This can be a tricky endeavor since you do not want to turn down available help however, the coordinator needs to be comfortable with sending volunteers out into the field. Some of the basic requirements I laid out proved to be very helpful such as setting an estimated time commitment, requiring volunteers to be able to carry 20 lbs. of equipment over a mile in the heat, and being able to drive at night discouraged several volunteers that I would not have been comfortable sending into the field.

Another limitation of volunteers was the need to simplify protocols and sampling procedures. The protocol that was developed for NABat was easily picked up by a majority of volunteers but its simplicity caused some limitations in the overall analysis. Using technicians that are experienced in field research allows for much more detailed site measurements that are more time consuming and more difficult to teach in a short training session. It was clear early in the process of scheduling volunteers that a series of training days for each volunteer was just unrealistic.

Although any coordinator that supervises technicians that are alone in the field has to be ready to assist them over the phone if issues arise, this project showed that volunteers can significantly increase this need. Volunteers were only trained in using sampling equipment once before they were scheduled to use it in the field. Although protocols were provided in each sampling kit and phone calls were made to verify a volunteer's readiness, the low amount of exposure may have caused a lack of confidence. A majority of the calls made while volunteers were in the field in 2017 were simple clarification or verification that something was being done properly. At the end of the day, it was important that volunteers were able to contact me and feel supported. I was eager to help with any issue regardless of how small which led to a lot of good laughs and increases in morale.

A serious concern with volunteers that could be a potential con but never resulted in issues in 2017, was that the increased number of people using the sampling equipment and trekking onto landowner's property increases risk for problems. With landowner involvement being such a high priority for the program there was some concern that sending more individuals out onto private property would increase our chances of a mistake (i.e. leaving a cattle gate open or walking through a neighbor's property) or that an unfavorable interaction with a landowner could occur. This coupled with the burden of how expensive and somewhat sensitive some of the equipment used can be is definitely worth discussing. This is an inevitable risk that comes from working with volunteers but can only be mitigated through good training. I was persistent in expressing the importance of respecting landowner property and the significant costs associated with equipment. Volunteers were perceptive and no issues occurred. This could however, be a challenge for the project in the future when more volunteers are added to the program.

Although there are several consequences or concerns involving volunteers for NABat there are a significant amount of positive benefits. The easiest positive benefit to point to is the reduction of cost to the NE NABat program. With an estimated $12,000 to be saved in mileage and labor costs each year, volunteers allow for resources to be allocated to maintaining, updating, and expand equipment while also expanding outreach. These savings can be crucial for the success of a long-term project such as NE NABat.

Including volunteers also provides the benefits of including the general public in science. A large portion of the public does not get the opportunity to participate in environmental science on a regular basis. Volunteers working with the NE NABat program are able to learn techniques and principles that most people only get to read about. This could be a great opportunity for young individuals that are looking to join the wildlife or natural resources job market but that lack experience. I believe that NE NABat can be a great recruitment tool used to introduce volunteers to wildlife careers and perhaps inspire them to pursue a career path in environmental science.

As with any involvement with the public the volunteers of NE NABat get a chance to receive in-depth information about bats from an expert. The information learned at trainings or in the outreach programs that connect NE NABat with volunteers can be spread to the friends and family of volunteers creating greater awareness. This information can be important to public opinion of bats in Nebraska since many topics covered included the benefits of bats to agriculture and people, and the issues associated with them experiencing significant decline. Since many of the volunteers that participated in NE NABat in 2017 were active members of their communities, this was also a great resource not only for the spreading of information but also for increasing connection with current or potential landowners that participate in the project.

Volunteers also increased collaboration between the Game and Parks Commission and important nonprofit organizations. Including volunteers in the program required equipment to be stored in easily accessible facilities and for trainings to be held in centralized areas that volunteers could get to. Including organizations like the Crane Trust or the Prairie Pines Nature Preserve answered these needs and provided an opportunity for collaboration. In 2017 while training volunteers I was able to have detectors left out at both the Crane Trust and Prairie Pines Nature Preserve in order to do a small survey for each group. Both organizations were very appreciative of the data and gladly allowed me to use their facilities. Collaborations such as these are beneficial since they provide future facilities for outreach, landowner presentations, and volunteer recruitment.

VOLUNTEERS – FEEDBACK AND TECHNICIAN COMPARISON

After volunteers had been through training and participated in sampling, I made it a priority to chat with them about what they thought about the program. All the volunteers that participated thought that the training was very useful and provided them with a majority of the information they needed to conduct sampling. Stationary deployments were an overwhelming favorite of volunteers. Many volunteers were happy to get the opportunity to do some light hiking for science and see parts of their region they may have never been to. Although I did my best to reduce the complexity of sampling site features around a stationary detector some volunteers were annoyed with having to measure so many trees through the point quarter method (see Chapter 2).

Other complaints about the project surrounded the driving transects. Some volunteers complained about how late they were getting home after they completed a driving transect which was completely understandable coming from a non-bat researcher perspective. Transects were driven 45 minutes after sunset which can range from about 8:45pm to 9:00pm depending on what day in the month of June or July that they were sampled. This translates to a transect starting at 9:30pm to 9:45pm, taking about 1.5 hours to be driven, and finishing around 11:00pm to 11:30pm. Since grid cells were not located where volunteers lived, they then had to drive half an hour to an hour to get home. These late nights were frustrating for a handful of volunteers. Although I had done my best to describe how late a driving transect would end and asked volunteers if they were comfortable with two late nights needed to complete a grid cell, a communication or understanding failure occurred. Of the 12 volunteers that participated in NE NABat in 2017 there were 7 that stated that they would be willing to participate in the project in the future and would be happy to complete both driving transects and stationary deployments, 4 that would be willing to participate if they did not have to do driving transects, and 1 volunteer that completed a cell but said they would not consider participating in the project in the future.

An added benefit of using technicians versus volunteers is the variation in what people are willing to do. Technicians are paid to do a job and sign an agreement that clearly states what their duties and responsibilities are, making managing them easier and more efficient. Volunteers on the other hand are donating their time so careful planning and consideration needs to be given to a much larger group of individuals. This can create problems from a coordinators perspective but if a focus on flexibility and adaptability is maintained a lot of good work can be accomplished.

Many researchers seem to be deterred by the idea of using citizen scientists to conduct research because of an assumption that good data will not be collected (Kosmala et al. 2016). This was not my experience throughout the 2017 field season. In fact, I would even argue that some of the data from volunteers ended up providing more detailed information. From my experiences from working with and being a technician in the past, there can be a point of stagnation over the course of a field season in the sections of data sheets that are optional, such as comments or site drawings for example. All of the specified elements that are still captured consistently but the work has become routine. Our data sheets had large boxes to allow for comments about a site including obstacles that future participants should be warned about (e.g., very wet site so bring knee high boots or use the gate to the west of the site for much easier access), comments about issues that occurred with equipment, and a spot for them to draw the site in case photos were lost. In the first dozen or so deployments, most technicians filled these boxes completely with lots of details however, as the season progressed and things become routine some of the initial detail was lost. This was not the case for most volunteers. The volunteers in 2017 consistently completed the more optional portions of data sheets. This was very beneficial for me as a coordinator to help prepare information packets specific to each cell and warn future volunteers of obstacles. I also learned from comments about which portions of data sheets were confusing or what aspects or details need to be added to future trainings. The main take home that I experienced in 2017 was that with good training and a simplified protocol, technicians and volunteers were both good and effective at conducting NE NABat but they are simply different.

Landowners

A large portion of the success of NE NABat can be attributed to the support and involvement from private landowners. The door to door method established in the beginning of the program was very successful with only 10 landowners denying permission to access their land. Perhaps this is just a result of "Nebraska Nice" and success would not be as high in other states, but I speculate that our approach had a lot to do with it. Approaching landowners as excited ecologist or students and not as authoritative researchers was a very effective approach and one that I would encourage other states to employ.

The personalized information packets that were sent to landowners were very well received and have strengthened many relationships. The phone calls that were made to each landowner sparked hours of conversations and sharing of information both from them and to them. In 2017, 96 of the original 100 landowners from 2016 participated in the NE NABat program. When discussing our reliance on private landowners with researchers from other states I usually receive gasps or disbelief when reporting our success and retention. I believe that the individual attention to each landowner was the main driving factor. I have received Christmas cards, requests for more resources to share with friends, and NABat has become a topic of conversation for many Sunday coffee meet ups around the state. The support of these individuals is paramount to the success of the program and this personable approach has been proven in Nebraska to be tremendously effective.

Future of NE NABat

NE NABat is proposed to continue as far into the future as funding, resources, and support will allow. To do this we will need to increase the number of volunteers that are sampling across the state, increase engagement with landowners in a public platform, increase the accessibility of information about the project, find creative solutions to supplement the volunteer workload, and modify the current sampling structure to better fit the restrictions and desires of a volunteer base. The experiences of 2016 and 2017 have provided a lot of ideas and lessons that should be adhered to in order to give the program the best opportunity possible to survive.

First of all, we are going to need a much larger group of volunteers to complete grid cells in the future. In order to accomplish this the future NE NABat coordinator will need to begin another large campaign to seek out volunteers. The Master Naturalist program will be one of the first places to continue looking for volunteers however many of the programs volunteers live in the Lincoln and Omaha regions and therefore are only able to sample a limited portion of the state. In order to branch out and obtain volunteers in the more rural or isolated areas of the state, collaboration with organizations like

Audubon Nebraska, Nature Conservancy of Nebraska, and Nebraska Land Trust will be key. Bat talks and outreach events are some of the key opportunities to find volunteers around the state and utilizing the facilities and networks of these organizations will be very beneficial moving forward.

Along the same thread as increasing volunteer numbers there is also a need to provide presentations to volunteers and landowners. Many programs that involve volunteers have the responsibility of presenting the results of data collected to those who were involved. Several of the volunteers that participated in NE NABat voiced these concerns since they had not been given this information after being involved in other projects in the past. In order to maintain a volunteer base, it is crucial that NE NABat provide results to landowners, volunteers, and the public. This should take the form of regional presentations at key towns within driving distance of participants. These presentations if done properly will likely increase excitement about the program and keep the public happy to continue their participation.

In order to increase accessibility to information about NE NABat, a website or webpage hosted by another entity's website should be developed. This could give a detailed description of the project and all its components and provide website links and more information about bats in general. This would also be an opportunity to highlight volunteers that have helped with the program, provide a resource for potential new volunteers to learn more about the project, and provide all necessary contact information for recruitment. The website could also be a location where results and figures are displayed for the public to view and learn about the results of the program.

The final modifications to NE NABat that would be very beneficial would be to increase the flexibility of how the tasks required for each grid cell are administered and removal of any site measurements that can be deleted without large impact. Flexibility can come in many forms but one of the key ways that was very evident from working with volunteers was driving transects. Since there was push back from some volunteers about conducting driving transects it might be a good idea to separate the two sampling procedures. Essentially you would have one volunteer complete stationary deployments and another driving transects. Volunteers that are willing and eager to do both should be encouraged to since it greatly reduces complexity for the coordinator. However, making it optional would most likely increase overall satisfaction for volunteers. On top of that change a consideration to remove some of the site measurements at the stationary deployments may prove to also improve satisfaction; however, careful consideration and discussion needs to be taken to make sure that important data are not lost or ignored.

Support for NE NABat has been overwhelming and has made me extremely excited for its future. Having the opportunity to work with so many interesting and passionate people has been one of the highlights of my life. As a non-native to Nebraska I have been baffled by the number of positive interactions I have had with the public and the passionate individuals at the states many organizations I have had the privilege to collaborate with. I am confident that with enough effort, funding, and continued support of Nebraska’s agencies and nonprofits there is a great future ahead for the NE NABat program.

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TABLES AND FIGURES

Table 1.1. Table of the land classifications used in site selection for stationary deployments in NE NABat. NE NABat land classifications were determined by simplifying the values found in Rain Water Basin Joint Venture GIS layers.

Nebraska NABat Land Classifications	Rain Water Basin Joint Venture
Cropland	38 Cropland
	201 Alfalfa
	202 Corn
	203 Fallow
	206 Sorghum
	208 Sunflowers
	209 Wheat
	211 Crop Other
Grassland	71 Mixed Grass
	73 Sandhills Grassland
	75 Short Grass
	77 Tall Grass
	87 Sand Sage
	31 CRP - Grasses
Wetland	12 Playas
	13 Sandhill Wetlands
	14 Rainwater Basins
	15 Other Wetlands
	121 Farmed - Wetlands
	122 Grassland/Buffered - Wetlands
	141 RWB Farmed - Wetlands
	142 RWB Early Successional - Wetlands
	143 RWB Late Successional - Wetlands
	152 Emergent Marsh
	153 Saline
Riparian	33 CRP - Trees Riparian
	241 Riparian Canopy
	242 Exotic Riparian Shrubland
	243 Native Riparian Shrubland
	244 River Channel
Developed	46 Urban/Suburban
	42 Rural Developed
Upland	61 Forest/Woodland (Upland)
	32 CRP - Trees Upland
Pine	63 Ponderosa Pine
	60 Many Trees, Little Grassy Understory
	69 Few Trees, Grassy Understory
Red Cedar	59 Eastern Red Cedar
	66 Juniper
Sparse	51 Badlands

Table 1.2. Table of equipment costs for NE NABat in 2016. This table shows all of the equipment that was necessary to start NE NABat.

Equipment Costs Start Up Year 2016

Category	Equipment	Qty	Unit Price	Description	Total Cost
Acoustic Detectors	Stationary Detectors	16	$ 870.00	Titley AnaBat Express units	$13,920.00
	Transect Detectors	4	$1,595.00	Titley AnaBat Walkabout units	$ 6,380.00
	Car Mounted Microphone	4	$ 785.00	Titley AnaBat Carmounts - External Microphone Adapters + Microphone	$ 3,140.00
	Extra Express Microphones	3	$ 185.00	Back up microphones for Express units	$ 555.00
	Extra Walkabout Microphones	2	$ 185.00	Back up microphones for Walkabout units	$ 370.00
	$24,365.00				
Power Supply	AA Rechargeables	160	$ 2.49	AmazonBasics AA Batteries	$ 398.40
	Battery Charging Stations	4	$ 35.99	Tenergy 16 Bay Charging Stations	$ 143.96
	Power inverter	4	$ 29.97	Power supply for backup charging of Titley Walkabout Detectors	$ 119.88
	$662.24				
Site Measurement Equipment	Digital Cameras	4	$ 149.00	Fuijifilm FinePix XP80 Digital Cameras	$ 596.00
	Handheld GPS	4	$ 212.99	Garmin GPSMAP 64 Handheld GPS Units	$ 851.96
	Meter Tape	4	$ 21.59	50 meter tape for site measurements	$ 86.36
	DBH Tape	4	$ 38.25	DBH tape	$ 153.00
	$1,687.32				
Stationary Deployment Equipment	Hammers	4	$ 19.30	Drilling Hammer - For placing stationary detectors	$ 77.20
	Mount Harware	-	-	Hardware for stationary Mounts + mending plates for Express units	$ 150.00
	Painters Poles	20	$ 32.28	6ft - 12ft locking painter’s poles	$ 645.60
	$872.80				
Volunteer Kit Equipment	SD Card Carrying Cases	4	$ 17.19	Pelican 0915Memory Card Case	$ 68.76
	Equipment Cases	5	$ 74.13	Seashorse Hard Cases	$ 370.65
	Backpacks	4	$ 49.95	REI backpacks	$ 199.80
	$639.21				
Miscellaneous	Car Magnets	4	$ 16.56	12" x 18" Customized Magnets for vehicles during transects	$ 66.24
	$66.24				
					Total: $ 28,292.81

Table 1.3. Table of relative vehicle costs for NE NABat in 2016 and 2017. Based on the mileage accrued during both the 2016 and 2017 field season the table below shows an estimate of the cost to conduct NE NABat based on the federal mileage rate and the average gasoline prices for each year summer.

Vehicle Costs

2016					
Vehicle	Month	Mileage	2016 Federal Mileage Rate (0.54/mile)	Gallons of gas	Avg gas price $2.25
Dodge Dakota 18mpg	May	93	$ 50.22	5.17	$ 11.63
	June	5030	$ 2,716.20	279.44	$ 628.75
	July	8098	$ 4,372.92	449.89	$ 1,012.25
	August	89	$ 48.06	4.94	$ 11.13
	Total:	13310	$ 7,187.40	739.44	$ 1,663.75
Chevy Colorado 19mpg	May	0	$ -	0.00	$ -
	June	2927	$ 1,580.58	154.05	$ 346.62
	July	8592	$ 4,639.68	452.21	$ 1,017.47
	August	0	$ -	0.00	$ -
	Total:	11519	$ 6,220.26	606.26	$ 1,364.09
Chevy 2500 18mpg	May	0	$ -	0.00	$ -
	June	748	$ 403.92	41.56	$ 93.50
	July	165	$ 89.10	9.17	$ 20.63
	August	0	$ -	0.00	$ -
	Total:	913	$ 493.02	50.72	$ 114.13
Totals					
Federal Rate					$13,900.68
Gas only					$3,141.97

2017					
Vehicle	Month	Mileage	2017 Federal Mileage Rate (0.535/mile)	Gallons of gas	Avg gas price $2.40
Dodge Dakota 18mpg	May	592	$ 316.72	32.89	$ 78.93
	June	3646	$ 1,950.61	202.56	$ 486.13
	July	4260	$ 2,279.10	236.67	$ 568.00
	August	1469	$ 785.92	81.61	$ 195.87
	Total:	9967	$ 5,332.35	553.72	$ 1,328.93
Chevy Colorado 19mpg	May	640	$ 342.40	33.68	$ 80.84
	June	1054	$ 563.89	55.47	$ 133.14
	July	1205	$ 644.68	63.42	$ 152.21
	August	958	$ 512.53	50.42	$ 121.01
	Total:	3857	$ 2,063.50	203.00	$ 487.20
Totals					
Federal Rate					$7,395.84
Gas only					$1,816.13
Change from 2016 to 2017					
Federal Rate					-$6,504.84
Gas only					-$1,325.83

Table 1.4. Table of estimated labor costs for NE NABat in 2016, 2017, and future years.

Labor

Startup Year 2016			
Exployee	Hourly Rate	Total Hours	Total Cost
Part Time Technician	10.5	160	$ 1,680.00
Full Time Technician	10.5	400	$ 4,200.00
GS 9 Salary			$43,251.00
Total			**$49,131.00**

Second Year 2017			
Employee	Hourly Rate	Total Hours	Total Cost
Full Time Technician	10.5	400	$ 4,200.00
GS 9 Salary			$43,251.00
Total			**$47,451.00**

Future Years	
Employee	Total Cost
GS 9 Salary	$43,251.00
Total	**$43,251.00**

Table 1.5. Cost comparison between 2016, 2017, and future years based on labor and vehicle costs. This table shows the saving accrued for incorporating volunteers into the NE NABat program and the removal of a field technician in future years.

Labor and Mileage

	Category	Total Cost
Startup Year 2016	Vehicle Costs - Federal Rate	$ 13,900.68
	Labor	$ 49,131.00
	Total	**$ 63,031.68**

	Category	Total Cost
Second Year 2017	Vehicle Costs - Federal Rate	$ 7,395.84
	Labor	$ 47,451.00
	Total	**$ 54,846.84**
	Savings compared to 2016	**$ 8,184.84**

	Category	Total Cost
Future Years	Vehicle Costs - Federal Rate	$ 7,395.84
	Labor	$ 43,251.00
	Total	**$ 50,646.84**
	Savings compared to 2016	**$ 12,384.84**

Cost Per Grid Cell by Year	Totals
2016	$ 1,800.91
2017	$ 1,567.05
Future Years	$ 1,235.74

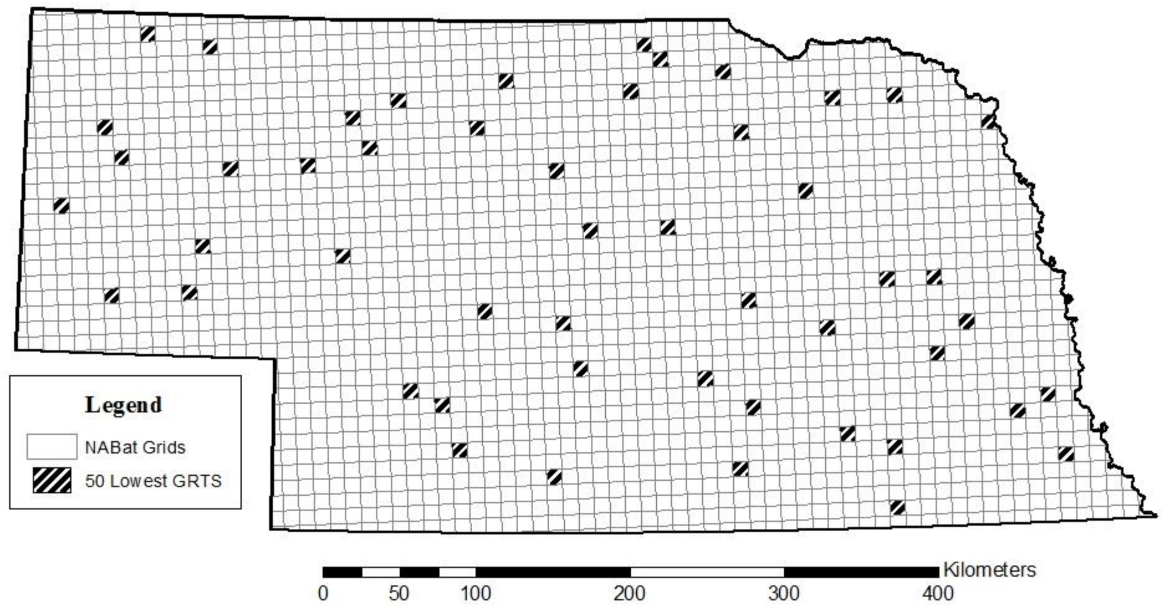

Figure 1.1. Map of the 50 grid cells with the lowest generalized random tessellation stratified (GRTS) values in the state of Nebraska. This sampling of cells was reduced to 35 suitable cells, starting with the lowest GRTS values, based on roads conditions and the success of getting in contact with landowners.

Figure 1.2. Photo of mount designed for Anabat Express units on a simple painter’s pole. A metal mending plate has been glued to the back of the Express unit using epoxy in order to provide additional structural support.

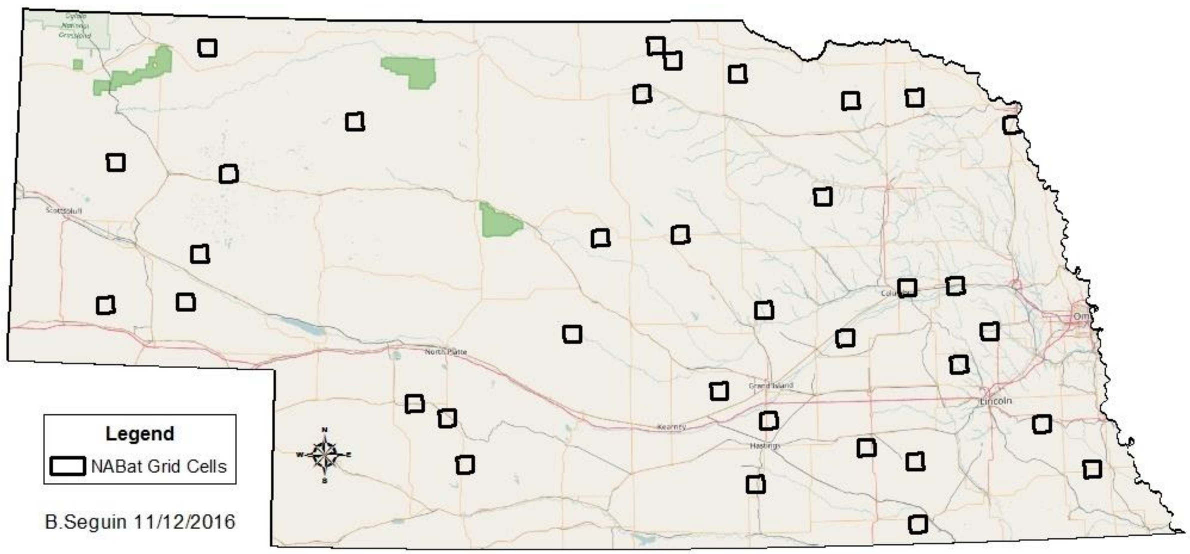

Figure 1.3. Map of the final 35 grid cells surveyed in 2016 and 2017. Each of these cells contains a driving transect route and between 2 and 4 established stationary detector locations.

CHAPTER 2: BAT ACTIVITY RESPONSE TO LANDSCAPE FEATURES ACROSS NEBRASKA

INTRODUCTION

The 11 species of bat commonly found in Nebraska are all insectivores and consume massive quantities of insects throughout the diverse ecosystems of Nebraska. Estimates of their economic contribution to agricultural systems globally are approximately over 3.7 billion dollar annually, so conserving their populations is likely beneficial not only to humans but the ecosystems they inhabit (Boyles et al. 2011, Maine and Boyles 2015). However, like many wildlife species in our increasingly anthropogenically influenced world, bats have suffered disturbance and habitat loss throughout the past century (Racey and Entwistle 2003, Weller et al. 2009). This disruption to their populations has occurred at an unprecedented level in the past two decades in North America with the emergence of two new threats, wind energy development and the disease white-nose syndrome (Blehert et al. 2009, Frick et al. 2010, Foley et al. 2011, Blehert 2012).

Wind energy development has increased in the past several decades and causes high levels of mortality in migratory and tree roosting bats like the silver haired bat (*Lasionycteris noctivagans*), eastern red bat *(Lasiurus borealis*), and hoary bat (*Lasiurus cinereus*) which are all common in Nebraska (Arnett et al. 2008, Arnett and Baerwald 2013, Hein and Schirmacher 2016). Some estimates have determined that 3-4 bats are killed at each wind turbine each year, which when extrapolated to the number of turbines in the country is a mortality rate that could have significant population impacts over time (Arnett et al. 2008, Hein and Schirmacher 2016). Unfortunately, unlike cave or building hibernating species that congregate in high concentrations in locations that have been monitored for decades, giving us relatively reliable population estimates, many of the migratory species are understudied and researchers have little to no idea how much wind energy is impacting them (Kunz et al. 2007).

White-nose syndrome (WNS), a disease caused by the fungus *Pseudogymnoascus destructans*, has caused catastrophic declines of cave and building hibernating bats since 2006 in the eastern portion of the U.S. (Frick et al. 2010). Since it was discovered in New York State the disease has spread across the United States and produced >70% mortality in a majority of the hibernacula that have been infected with some species reaching 99% mortality (Frick et al. 2010, Fisher et al. 2012). These challenges mean that largescale efforts that cross state boundaries need to be implemented in order to conserve bat habitat and influence their recovery or we may be facing an extinction event in North America with potentially significant ecological and agricultural ramifications (Coleman et al. 2011).

Large scale monitoring programs that focus on bats have not been previously established, however they may provide tools to conserve bat habitat. In Nebraska the North American Bat Monitoring Program (NABat) provided an opportunity to establish a state wide monitoring protocol (Loeb et al. 2015). Many studies have been conducted in Nebraska to study the life history and habitat of bats but very few projects have been conducted statewide and have had an emphasis on acoustic detectors which allows for sampling in areas that mist netting would be unsuccessful (Benedict et al. 2000, Benedict 2004, Geluso 2006, Geluso and Geluso 2012, Geluso et al. 2013). The NE NABat program fills both of these roles while allowing for the involvement of volunteers to further awareness about bats, their importance, and the issues facing them today.

This study focuses on stationary ultrasound acoustic detectors that record bat echolocation that can be identified to the species level using sophisticated software. Through a diversity of sites with various habitat features found throughout Nebraska I set out to determine if landscape characteristics were influencing the activity of bats on the Nebraska landscape. The establishment of this work will lay a foundation that the future NE NABat program can build from and produce more species specific questions that are answerable by the NE NABat data.

This study focused on 6 species with very different foraging techniques and life histories; I hypothesized that all of the species would respond similarly to the landscape of Nebraska. I hypothesized that bat activity would be positively associated with higher forest area, taller/more abundant trees, and water that was nearby and accessible to bats. I also hypothesized that bat activity would have a negative relationship with grassland and cropland and that more noise and more cluttered environments around detectors would decrease their effectiveness at recording echolocation and in turn reduce recorded bat activity. I also hypothesized that bat activity would be negatively correlated with eastern red cedar. Although this invasive tree provides wind barriers that are commonly used by insects and bats, I believe that the structure of the trees makes them difficult for bats to utilize as roosts since it is likely difficult for them to reach the trunk of the tree. Therefore, I hypothesized that bat activity would be lower in areas heavily dominated by Eastern redcedar

The ground work of the establishment of NE NABat provided a baseline and avenue for the continued conservation of Nebraska bats. Through pulling from the immense dataset that is produced by the NE NABat program we will be able to address a multitude of questions in the future and produce models that can aid managers and policy. In this crucial time of intense anthropogenic influence on our planet programs such as these that can bolster public support and provide a framework for good science are critical.

METHODS

I conducted a series of mixed effect models based on the activity rate of bats at stationary acoustic detector locations throughout Nebraska. Models were created based on 4 spatial scales in order to determine the variables that influence activity levels of a species. Models were the same for each species in order to better facilitate comparisons between species. Of the 11 species commonly found in the state, 6 had sufficient sample sizes for modeling including the big brown bat (*Eptesicus fuscus*), eastern red bat (*Lasiurus borealis*), silver-haired bat (*Lasionycteris noctivagans*), hoary bat (*Lasiurus cinereus*), evening bat (*Nycticeius humeralis*), and northern long-eared bat (*Myotis septentrionalis*). This study focused on some of the key characteristics associated with bats in other parts of the country such as forest and water. However due to open environments such as grassland and cropland dominating much of the Nebraska landscape I placed a large emphasis on determining what influence they had on bat activity.

STUDY AREA AND SITE SELECTION

I utilized the framework of the North American Bat Monitoring Program (NABat) to establish a state specific Nebraska NABat (NE NABat). The core of the Nebraska NABat program follows the methodology outlined Loeb et al. (2015). NABat utilizes 10 km x 10 km grid cells that were first developed by the Forest Service and the U.S. Department of Agriculture for a monitoring program in the Pacific Northwest (Ormsbee et al. 2006, Hayes et al. 2009, Rodhouse et al. 2012). The grid was expanded across North America in order to establish a master sample (Larsen et al. 2008, Loeb et al. 2015). These 100 km^2 grids are considered a sufficient size for modeling and mapping bat species distributions at course geographic scales (Rodhouse et al. 2012). In order to incorporate a random and geographically balanced sample across the continent, the NABat team assigned values to each grid using the generalized random-tessellation stratified (GRTS) survey design algorithm (Stevens and Olsen 2004). Subsamples of the master sample can then be pulled based on a distinct geographic location, which for my purposes was the state of Nebraska (Figure 2.1). This methodology weights cells with lower values based on randomization and increased geographic spatial balance. Therefore, a new project can easily select locations in a region by simply selecting the lowest GRTS value cells. GRTS allows for grid cell addition and subtraction as monetary resources, landowner permission, or other unforeseen changes occur over the course of a long-term monitoring project. Using the grid system, I selected the 50 grid cells with the lowest GRTS value with an end goal of at least 30 established cells after the first year of sampling (Figure 2.1).

Within each grid cell stationary detector locations were assigned and monitored each year. Between 2-4 stationary acoustic detectors were deployed for at least 4 nights in each grid cell between the months of June and July each year to sample the resident population during the maternity season. The NABat protocol places an emphasis on these detectors being placed in diverse locations in order to ensure they capture all the bat diversity within the grid cell.

To capture bat diversity within each grid cell while also including spatial balance and randomization I applied the GRTS survey design algorithm to land cover classifications. Using the USGS 2011 National Land Cover Database I simplified their land classifications into groups that reflected the 9 dominant land cover types in Nebraska where detectors could be effectively placed (U.S. Geological Survey 2014) (Table 2.1). By calculating the area of each of these land classification groups I was able to determine which four were dominant (by area) in the grid cell. Each of the four dominant land cover classifications of a cell were then sampled using a single stationary detector. If a cell contained only three classifications, then the highest classification by area would receive a second detector. If the cell contained only two classifications, then each classification would receive two detectors. No cells had fewer than two land cover classifications. To reduce selection bias that could be generated by landowners that were easy to contact, perceived excellent bat habitat, or proximity to one another I utilized the same GRTS survey design algorithm used for the larger NABat 10 km by 10 km grid selection (Stevens and Olsen 2004). Through combining the areas under the same classification and assigning GRTS points within the polygons I was able to use the same number ranking system to accept or reject sites based on their proximity to the road, landowner permission, and verification that the land classification actually matched on the ground observations. This created an ideal random sampling structure that added organization and a systematic approach to cycling through dozens of landowners.

EQUIPMENT

For Nebraska NABat I used 16 Anabat Express (Titley Scientific) zero crossing bat detectors for stationary deployments. These detectors were attached to an extendable 1.8-3.6 m painter's poles using a simple bracket. Although this is a shorter pole than many studies use, the short overall length made transporting poles by volunteers much easier along with widening the range of vehicles that volunteers could use. Anabat Express units were selected because they are easy to setup, have a battery life of 8-10 days, and reduce data storage needs because they record zero crossing files.

Detector Deployment

Detectors were placed in each of the dominant land classifications by area in each cell. An emphasis was placed on putting detectors in more open areas where clutter would not decrease the ability to identify species. At each site location a GPS point was taken along with 5 groupings of measurements related to tree density, water, and clutter for the area within 30m of the detector. Tree density was measured using the point quarter method, in which the distance to the closest 4 trees and their DBH were measured in four quadrants surrounding a detector. Canopy closure was recorded above each detector and at a point 30m in each for directions based on where the detector was facing in the form of binned values 0%, <25%, 26 – 50%, 51-75%, and >75%. Water at a site was recorded in two ways. The type of water present was recorded in four categories within two groups: stationary water was either perennial or ephemeral, and moving water was either a stream or river. If no water was recorded it was marked none. Accessibility to water was also recorded in 4 categories: 0 no water present, 1 water present but completely covered by vegetation and not accessible by bats, 2 water present but partially covered by vegetation, and 3 completely open water readily accessible to bats. The distance to clutter in each direction (up, down, and each cardinal direction) was also recorded in bins, <2.5m, 2.6-5m, 5 – 10m, >10m. Only three of these variables were used in this study due to complications and issues with correlation.

LANDSCAPE FEATURE COVARIATES

Using ArcGIS I was able to look at the area surrounding each detector and determine variables that might influence bat activity. The first variable was distance to water. Using the Rainwater Basin Joint Venture GIS layers, I did a distance to nearest join to the stationary points after reclassifying all water types into 1 and non-water into 0 (Bishop et al. 2011). Also using the Rainwater Basin Joint Venture GIS layers, I established a series of buffer radiuses around each stationary point at 500m, 1.5km, and 5km. I then reclassified the Rainwater Basin Joint Venture layers into an all trees layer, an all cropland layer, an all grassland layer, and an all eastern red cedar (*Juniperus virginiana*) layer. For each buffer radius I calculated the number of cells that were of each classification since this directly related to the area of each land classification within the buffer. I also utilized the LANDFIRE Canopy Height GIS layers from the U.S. Department of Interior Geological Survey at each buffer radius (LANDFIRE: LANDFIRE Forest Canopy Height Layer 2013). This layer provides the estimated canopy height for trees. For each stationary point buffer, I calculated the mean value from the LANDFIRE layer so that presence of trees and height of trees could be combined into one value from now on referred to as the height/presence of trees. The tree area and tree height/presence values were slightly correlated but they are responses to different circumstances so I left them within the analysis. Table 2.2 shows each variable and the corresponding characteristics.

ACOUSTIC ANALYSIS

Auto classification was used to identify species from the stationary detector deployments. Kaleidoscope pro 4.1 from Wildlife Acoustics was used for all auto classification. Settings were set to liberal, 5 minimum pulses, 8-120 kHz, and a gap between pulses of 2-500ms. After auto identification was completed by Kaleidoscope my colleagues Michael Whitby, Zachary Warren, and I created a validation procedure to further limit identification of poor quality calls. Based on the number of pulses from an original file and the match ratio for a specific species, these values were converted into a score for that species for each night. If a file contained a call with 10 or more pulses and a match ratio of 0.9 or higher it received a 0.5 score, one with 5 or more pulses and a match ratio of 0.75 received a 0.333 score, one with 5 or more pulses that had a match ratio of 0.5 received a 0.25 score, and any file with a match ratio of less than 0.5 was converted into a NoID. If the total score for that night of recording for a specific species reached 1.0 or more then the files were left to contribute to the overall activity for that species at that site. If the score did not reach 1.0 for a species, then the files were re labeled as NoID. This process allowed for easy removal of nights that only had a small number of calls identified as a specific species and contributed to removing poor quality calls.

Many of the sampling periods were different throughout the study and detectors sampled for between out for 4-9 nights. Thus I used an activity rate approach. Using the log files from the Anabat Express units, I extracted the length of recording time for each night. I then divided the number of calls for each species by the total hours of survey effort. This resulted in a rate for each site in year 1 and year 2. This value was then transformed using log10(+1) in order to normalize the distribution.

Modeling Approach

I utilized mixed effect models for this analysis. Since I was attempting to define how activity rates of each bat species varied in response to site and landscape variables around each site across the state, I incorporated a random effect of site corresponding to the unique site codes for each stationary deployment. This allowed each site to have a different intercept. Models were assessed using a model selection approach at each of the scales, Site, 500m, 1.5km, and 5km. All of the models created were kept the same across species in order to allow for comparison. The models that utilized landscape variables (i.e. 500m, 1.5km, and 5km) were kept the same across scales with only the size of area looked at for each variable changed. A list of the models and their corresponding hypothesis can be seen in Table 2.3.

Model Selection Approach

Models were selected using the Akaike information criterion (AIC). All the models for each scale (Site, 500m, 1.5km, and 5km) were compared against one another with the addition of a global model for that scale and a null model. Models were selected if they had a delta AIC value < 2. After selecting the top model from each scale, I then compared them against one another using the AIC method again. In the final AIC model selection process I created a global model that contained all of the variables from the study and another null model. Final conclusions were based on both the models selected at each scale and the final model produced.

Results

Survey Results

I surveyed 35 NABat grid cells in 2016 and 2017. The average number of stationary deployment sites for each grid was 3.6 in the first year and 3.4 in the second year. In total, 126 unique sites were surveyed in 2016 and 120 unique sites were surveyed in 2017. Of the 126, 7 sites were dropped because of difficulties reaching landowners or loss of permission from landowners with one site being replaced by a new landowner. A majority of the sites in 2017 were in the same location as 2016 with the exception of 6 sites that were shifted to new locations nearby because of landowner request, obtaining a better recording environment, or hazards that would have made sampling difficult for a volunteer to accomplish.

After applying the auto identification correction procedure, 30 of the 245 total sample points had zero bat activity. Twenty-six of these samples were located in the western half of the state. Although there are large stretches of area in western Nebraska that have ideal bat habitat, the NABat grid selection process did not always fall in those locations. Some of the cells sampled were several kilometers from any patch of area with over a handful of trees and only houses would be able to provide roost structures for bats. Although the grid cell process was very successful at capturing bat diversity and abundance in eastern Nebraska this was not necessarily the case in a majority of the Western cells.

Issues

Correlation was present in the tree data collected at the site level. Tree density calculated using the point quarter method was highly correlated with canopy closure at the five points near each detector. This was not a surprising result. The canopy closure variable was selected to be used since fewer NA's were recorded by technicians and volunteers. This is due to obstacles such as rivers or cliffs blocking volunteers and technicians from accessing specific trees with a measuring tape. Walking around obstacles however and reaching the location needed for a canopy closure value was much more feasible resulting in less NA's overall.

Some confusion from volunteers on the water type variable resulted in its removal from analysis. Although in training the water type was split into two major categories non-moving and moving this was not clearly outlined on the data sheets given to volunteers. This resulted in some confusion and the labeling of moving bodies of water as perennial opposed to stream or river. Although volunteers were right that river or stream could be considered perennial it did not match with the goal of separation in the study design. This confusion led me to remove the water type variable from this analysis.

BIG BROWN BAT (EPTESICUS FUSCUS)

The big brown bat was recorded frequently throughout most of the sites in this study. The top models selected in the site scale model set were model 2 and the Global model (Table 2.4). The site model 2 looks at the relationship between big brown bat activity and canopy closure, water access, and location (Latitude and Longitude) (Table 2.3). The site model 2 had a delta AIC score of 0 with a weight of 0.537 (Table 2.4). All of the variables in the site model 2 had p values of < 0.02 and the slopes associated with each variable were all positive.

For the 500m and 1.5km scales the Global model in both cases was selected as the top model (Table 2.4).

For the 5km scale model set model 8 and the Global model were both selected (Table 2.4). The 5km model 8 included grassland area, cropland area, height and presence of trees, and the distance to water (Table 2.3). The 5km model 8 had a delta AIC value of 0 with a weight of 0.595 (Table 2.4). All of the variables in 5 km model 8 had a significant p value with the exception of distance to water. In model 8 there was a small negative relationship between activity, cropland area, grassland area, and distance to water, and a strong positive relationship between tree height and presence and activity. The final model selected for the big brown bat was the overall Global model which contained all 23 variables assessed in this study (Table 2.5 and Table 2.6).

EASTERN RED BAT (LASIURUS BOREALIS)

The Eastern red bat was also recorded quite frequently at many of the sites in this study. The top model selected for the Eastern red bat in the site scale model set was model 2 (Table 2.7). Site model 2 tested the relationship between Eastern red bat activity, canopy closure, water access, and location (Latitude and Longitude) (Table 2.3). Site model 2 had a delta AIC value of 0 and a weight of 0.850 (Table 2.7). Out of the four variables in site model 2 only water access and Longitude had significant p values and both had positive relationships with Eastern red bat activity.

For the 500m scale model set model 9 and the Global model were selected (Table 2.7). The 500m model 9 assessed the relationship between Eastern red bat activity, grassland area, cropland area, tree area, and distance to water (Table 2.3). The 500m model 9 had a delta AIC value of 0.28 and a weight of 0.319 (Table 2.7). Out of the four variables in the 500m model 9 only grassland area, distance to water, and tree area had significant p values. In the 500m model 9 grassland area, cropland area, and distance to water had small negative relationships with Eastern red bat activity, and tree area showed a small positive relationship.

The top models selected for the 1.5km model set were model 7 and the Global model (Table 2.7). The 1.5km model 7 assessed the relationship between Eastern red bat activity, tree area, and distance to water (Table 2.3). The 1.5km model 7 had a delta AIC value of 1.30 and a weight of 0.273 (Table 2.7). Both tree area and distance to water in the 1.5km model 7 had significant p values and both had very small relationships with Eastern red bat activity, however, tree area had a positive relationship and distance to water had a negative relationship.

The top model selected for the 5km scale was the Global model (Table 2.7). The final model selected for the Eastern red bat based on the scale model selections was the overall Global model which contained all 23 variables assessed in this study (Table 2.8 and Table 2.9).

Hoary Bat (*Lasiurus cinereus*)

The top model selected for the hoary bat in the site scale model set was model 2 (Table 2.10). Site model 2 looked at the relationship between hoary bat activity, canopy closure, water access, and location (Latitude and Longitude) (Table 2.3). Site model 2 had a delta AIC value of 0 and a weight of 0.849 (Table 2.10). Of the four variables in site model 2, only canopy closure did not have a significant p value. Canopy closure in site model 2 had small positive relationship with hoary bat activity, however, water access, Latitude, and Longitude all had significant positive relationships with hoary bat activity.

For the 500m scale model set model 1, model 2, model 8, and model 9 were selected (Table 2.10). The 500m model 1 assessed the relationship between hoary bat activity, cedar area, grassland area, cropland area (Table 2.3). The 500m model 1 had a delta AIC value of 0.43 and a weight of 0.248 (Table 2.10). Of the three variables in 500m model 1, only grassland area and cropland area had significant p values. In the 500m model 1 cedar area, grassland area, and cropland area had small negative relationships with hoary bat activity. The 500m model 2 assessed the relationship between hoary bat activity, cedar area, grassland area, cropland area, and distance to water (Table 2.3). The 500m model 2 had a delta AIC value of 1.05 and a weight of 0.182 (Table 2.10). Only two variables in 500m model 2 had significant p values, grassland area and cropland area. All of the four variables in 500m model 2 had small negative relationships with hoary bat activity. The 500m model 8 looks at the relationship between grassland area, cropland area, average tree height and presence, and distance to water (Table 2.3). The 500m model 8 had a delta AIC value of 0 and a weight of 0.308 (Table 2.10). In 500m model 8 only grassland area and cropland area had significant p values. In 500m model 8 grassland area, cropland, and distance to water all had small negative relationships with hoary bat activity, however, there was a positive relationship found with average tree height and presence. The 500m model 9 looked at the relationship between grassland area, cropland area, average tree area, and distance to water (Table 2.3). The 500m model 9 had a delta AIC value of 0.88 and a weight of 0.198 (Table 2.10). In 500m model 9 only grassland area and cropland area had significant p values. In 500m model 9 grassland area, cropland, and distance to water all had small negative relationships with hoary bat activity, however, there was a positive relationship found with tree area.

The top models selected for the 1.5km model set were model 1 and model 8 (Table 2.10). The 1.5km model 1 assessed the relationship between hoary bat activity, cedar area, grassland area, cropland area (Table 2.3). The 1.5km model 1 had a delta AIC value of 0 and a weight of 0.444 (Table 2.10). Of the three variables in 1.5km model 1, only grassland area and cropland area had significant p values. In 1.5k model 1 cedar area, grassland area, and cropland area had small negative relationships with hoary bat activity. The 1.5km model 8 looks at the relationship between grassland area, cropland area, average tree height and presence, and distance to water (Table 2.3). The 1.5km model 8 had a delta AIC value of 1.97 and a weight of 0.166 (Table 2.10). In 1.5km model 8 only grassland area and cropland area had significant p values. In 500m model 8 grassland area, cropland, and distance to water all had small negative relationships with hoary bat activity, however, there was a positive relationship found with average tree height and presence.

The top models selected for the 5km scale were model 5, model 8, model 9, and the Global model (Table 2.10). The 5km model 5 looked at the relationship between hoary bat activity, average tree height and presence and tree area (Table 2.3). The 5km model 5 had a delta AIC value of 1.06 and a weight of 0.182 (Table 2.10). Both Average tree height and presence and tree area had significant p values, height had a small positive relationship with hoary bat activity while tree area had a very small positive relationship with bat activity. The 5km model 8 looks at the relationship between grassland area, cropland area, average tree height and presence, and distance to water (Table 2.3). The 5k model 8 had a delta AIC value of 0 and a weight of 0.310 (Table 2.10). In 5k model 8 only grassland area and cropland area had significant p values. In 5k model 8 grassland area, cropland, and distance to water all had small negative relationships with hoary bat activity, however, there was a positive relationship found with average tree height and presence. The 5k model 9 looked at the relationship between grassland area, cropland area, average tree area, and distance to water (Table 2.3). The 5km model 9 had a delta AIC value of 1.45 and a weight of 0.150 (Table 2.10). In 5km model 9 only grassland area, cropland area, and tree area had significant p values. In 500m model 9 grassland area, cropland, and distance to water all had very small negative relationships with hoary bat activity, however, there was a small positive relationship found with tree area.

The final model selected for the hoary bat based on the scale model selections was site model 2 (Table 2.11 Table 2.12). Site model 2 as described above assessed the relationship between hoary bat activity, canopy closure, water access, Latitude, and Longitude (Table 2.3). The relationship between the site model 2 variables and hoary bat activity can be seen in Figure 2.2.

Silver-haired Bat (Lasionycteris noctivagans)

The top model selected for the silver-haired bat in the site scale model set was the Global model (Table 2.13). For the 500m scale model set model 1, model 2, and the Global model were selected (Table 2.13). The 500m model 1 assessed the relationship between silver-haired bat activity, cedar area, grassland area, cropland area (Table 2.3). The 500m model 1 had a delta AIC value of 0.07 and a weight of 0.375 (Table 2.13). All three variables in 500m model 1 had significant p values. In 500m model 1 cedar area, grassland area, and cropland area had small negative relationships with silver-haired bat activity. The 500m model 2 assessed the relationship between silver-haired bat activity, cedar area, grassland area, cropland area, and distance to water (Table 2.3). The 500m model 2 had a delta AIC value of 0 and a weight of 0.388 (Table 2.13). All variables in 500m model 2 had significant p values with the exception of distance to water. In 500m model 2 cedar area, grassland area, cropland area and distance to water had small negative relationships with silver-haired bat activity.

The top models selected for the 1.5km model set were model 1, model 2, and the Global model (Table 2.13). The 1.5km model 1 had a delta AIC value of 0 and a weight of 0.388 (Table 2.13). All three variables in 1.5km model 1 had significant p values and all of them had a small negative relationship with silver-haired bat activity. The 1.5km model 2 had a delta AIC value of 0.26 and a weight of 0.341 (Table 2.13). Just as in the 500m model set, the 1.5km model 2 had significant p values for cedar area, grassland area, and cropland area, however, distance to water did not. All of the variables in 1.5km model 2 had a small negative relationship with silver-haired bat activity.

The top model selected for the 5km scale was the Global model (Table 2.13). The final model selected for the silver-haired bat based on the scale model selections was the overall Global model which contained all 23 variables assessed in this study (Table 2.14 Table 2.15).

NORTHERN LONG-EARED BAT (MYOTIS SEPTENTRIONALIS)

The northern long-eared bat was a relatively rare species recorded during this study. The top models selected for the northern long-eared bat in the site scale model set were model 2 and the Global model (Table 2.16). Site model 2 assessed the relationship between northern long-eared bat activity, canopy closure, water access, and location (Latitude and Longitude) (Table 2.3). Site model 2 had a delta AIC value of 0 and a weight of 0.583 (Table 2.16). Only canopy closure and latitude had significant p values, and both variables had positive relationships with northern long-eared bat activity. Water access had a small negative relationship with northern long-eared bat activity, however, longitude showed a positive relationship.

For both the 500m and 1.5km scale model sets the Global model was selected for the northern long-eared bat activity.

The top models selected for northern long-eared bat activity at the 5km scale were model 1 and model 2 (Table 2.16). The 5km model 1 assess the relationship between northern long-eared bat, Eastern redcedar area, grassland area, and cropland area (Table 2.3). The 5km model 1 had a delta AIC value of 0 and a weight of 0.620 (Table 2.16). Only eastern redcedar area had a significant p value; eastern redcedar had a small positive relationship northern long-eared bat activity. Both cropland area and grassland area at this scale had very small negative relationships with northern long-eared bat activity. The 5km model 2 assess the relationship between northern long-eared bat, Eastern redcedar area, grassland area, cropland area, and distance to water (Table 2.3). The 5km model 2 had a delta AIC value of 1.99 and a weight of 0.229 (Table 2.16). Like model 1 at this scale only the eastern redcedar area variable had a significant p value, this variable also had a small positive relationship northern long-eared bat activity. Both cropland area and grassland area at this scale had very small negative relationships with northern long-eared bat activity. Distance to water had a very small positive relationship.

The final model selected for the northern long-eared bat based on the scale model selections was the 500m Global model which contained all 7 variables in the 500m scale model set (Table 2.17 and Table 2.18). The relationship between each variable and northern long-eared bat activity can be seen in Figure 2.3.

EVENING BAT (NYCTICEIUS HUMERALIS)

The top models selected for evening bat activity at the site scale were model 9 and the Global model (Table 2.19). Site model 9 asses the relationship between evening bat activity, rate of noise files, water access, and canopy closure (Table 2.3). Site model 9 had a delta AIC value of 1.61 and weight of 0.307 (Table 2.19). In site model 9 all three variable in this mode had significant p values and strong positive relationships with evening bat activity.

The top models at the 500m scale were model 1, model 2, model 8, and the Global model (Table 2.19). The 500m model 1 assessed the relationship between evening bat activity, Eastern redcedar area, grassland area, and cropland area (Table 2.3). The 500m model 1 had a delta AIC value of 0 and a weight of 0.276 (Table 2.19). Both cropland area and grassland area had significant p values however, Eastern redcedar did not. All three variables had a small negative relationship with evening bat activity. The 500m model 2 assess the relationship between evening bat activity, Eastern redcedar area, grassland area, cropland area, and distance to water (Table 2.3). The 500m model 2 had a delta AIC value of 0.86 and a weight of 0.180 (Table 2.19). Both cropland area and grassland area had significant p values, however, Eastern redcedar and distance to water did not. All four variables had a small negative relationship with evening bat activity. The 500m model 8 assess the relationship between evening bat activity, grassland area, cropland area, average tree height and presence, and distance to water (Table 2.3). The 500m model 8 had a delta AIC value of 1.09 and a weight of 0.160 (Table 2.19). Only grassland area had significant p values, cropland area, average tree height and presence, and distance to water did not. All four variables had a small negative relationship with evening bat activity, except average tree height and presence which had a small negative relationship.

The top models at the 1.5km scale were model 5 and the Global model (Table 2.19). The 1.5km model 5 looked at the relationship between average tree height and presence and tree area (Table 2.3). The 1.5km model 5 had a delta AIC value of 0.98 and a weight of 0.211 (Table 2.19). Both variables had significant p values associated with evening bat activity. Tree area had a small negative relationship with evening bat activity while average tree height and presence has a small positive relationship.

The top models at the 5km scale were model 3, model 5, and model 6 (Table 2.19). The 5km model 3 assess the relationship between evening bat activity and average tree height and presence (Table 2.3). The 5km model 3 had a delta AIC of 1.05 and a weight of 0.233 (Table 2.19). Average tree height and presence had a significant p value and positive relationship evening bat activity. The 5km model 5 assess the relationship between evening bat activity and average tree height and presence and tree area (Table 2.3). The 5km model 5 had a delta AIC of 0 and a weight of 0.394 (Table 2.19). Average tree height and presence had a significant p value and positive relationship with evening bat activity. Tree area did not have significant p value and had a very small negative relationship with evening bat activity. The 5km model 6 assess the relationship between evening bat activity and average tree height and presence and distance to water (Table

2.3). The 5km model 6 had a delta AIC of 1.58 and a weight of 0.179 (Table 2.19). Average tree height and presence had a significant p value and positive relationship evening bat activity. Distance to water did not have significant p value and had a very small negative relationship with evening bat activity.

The final models selected for the evening bat based on the scale model selections was the Site Global model (Table 2.20 and Table 2.21) and site model 9 (Table 2.20 and Table 2.22). The relationship between each variable in the site Global model and evening bat activity can be seen in Figure 2.4. The site model 9 looks at the relationship between evening bat activity, rate of noise files, water access and canopy closure. The relationship between each variable in the site model 9 and evening bat activity can be seen in Figure 2.5.

DISCUSSION

BIG BROWN BAT

The big brown bat showed the most predictable pattern of any of the species analyzed. At the site level there was a significant positive relationship to both canopy closure and presence/access to water. This is a very logical result since more forest and water suits the needs of most bats. These two features provide food in the form of insects since they are more protected from the wind, have plenty of locations for night roosts or day time roosts, and provide water to meet their hydration needs. The only hypothesis based model in the landscape scales was Model 8 in the 5km buffer model set. This model said that big brown bat activity was negatively correlated with higher cropland and grassland area and being farther from water. There was also a positive correlation with average tree height being higher. In general activity for the big brown bat increased when cropland and grassland decreased and it increased in response to water being closer and an increase in the height/presence of trees. Unfortunately, the overall global model was selected as the final model which does not reveal much information. Further investigation of these sites in the future could lead to more distinct conclusions about how to manage for them however the results here are quite straight forward.

Eastern Red Bat

The eastern red bat responded to site variables in a similar way to the big brown bat. Higher canopy closure and present/accessible water increased their activity at sites. At the landscape scale however the eastern red bat had a heavier emphasis on more area of trees than the height/presence. Across all of the landscape models this was true. The significance of a positive Longitude trend showing more eastern red bats in the eastern side of the state could also aid in explaining this result. Unfortunately, the overall Global model was selected as the final model for this species what does not reveal a lot of information. The eastern portion of Nebraska is filled with lots of trees that border agricultural fields. This is likely an ideal location for this species since they are able to access a wide variety of roosts since there is a significant amount of area of trees and they do not have to fly far to reach another small stand. This result from this analysis shows that a higher amount of contiguous or connected forest is needed to increase activity levels for this species.

Hoary Bat

The Hoary bat selected multiple hypothesis based models in the scale based model selections. The final model selected was Model 2 from the site scale model set (Table 10 and Table 11). This model showed that hoary bat activity increased when presence of open water was in the area, canopy was more closed around the detector and if the detector was located more to the North and East of the state (Figure 2). Due to this bat being a large high flying species it might be possible that I was more likely to record this species when it comes down closer to the ground to get water. The detectors used in this study are only 3.6 meters off the ground when the painter's poles are fully extended which limits their ability to record higher flying bats. That would explain such a strong correlation with open water being in the vicinity increasing their activity levels. In the other models selected at each scale the hoary bat was responding negatively to higher amounts of cropland and grassland which also follows the known life history of this species being an above canopy forager.

SILVER-HAIRED BAT

The silver-haired bat had a similar relationship to variables as the hoary bat but the overall Global model was the final selected model for this species. At the 500m and1.5km scale this species was responding negatively to both cropland area and grassland area. This species is a forest bat which fits with these results. Unfortunately, not many conclusions can be made in this study due to the selection of the overall global model as the final model selected.

EVENING BAT

The final models selected for the evening bat were the site model 9 and the site global model. The models found significance in a positive relationship with canopy closure and water presence/access which was expected however it also had a positive relationship with the rate of noise files. This is a relationship that occurred in the silver-haired bat but there does not seem to be any stand out reasons for why the relationship occurred. More noise could mean more insects which would be beneficial for a bat species however usually more noise files is assumed to be negatively related to a species activity since detectors have a more difficult time record bats. This study not find that relationship, however. The landscape variables were similar to other species in that the evening bat responded positively to forest height/presence however it responded negatively to forest area. The evening bat occupies a similar kHz range as the eastern red bat which had a positive relationship to forest area. Is it possible that this is a result of inter species competition? It is possible that the similarity in echolocation frequency is causing these bats to occupy different locations from one another. This is an interesting result in the data that deserves more investigation to explain it.

Northern Long-eared Bat

The northern long-eared bat exhibited some of the stranger results that required some more investigation. In the 500m model the northern long-eared bat showed a not surprising result of being associated positively with forest area. As an interior forest species more trees in the span of a location should be able to explain their activity levels. However, no other variables showed significance aside from a positive relationship with eastern red cedar and average tree height and presence. Surprisingly the northern long-eared bat showed the same relationship to cedar across all of the other landscape based models. Since all of the other species showed a negative relationship to cedar I decided to look closer.

Unfortunately, there was a very small sample size of northern long-eared bats in this study. Out of the 185 data points analyzed for the northern long-eared bat only 27 contained their calls or 14%. Because of this the few sites that had the northern long-eared present heavily influenced the models. Many of the sites where northern long-eared bats were recorded resided in the Northeastern corner of the state. This is not necessarily a result of their presence on the landscape being restricted to the Northeast but the random selection process of GRTS only providing a handful of large contiguous forest sites. In the Northeastern corner of the state near the Niobrara river there is an interesting dynamic of trees. In the more valley like locations there are large swaths of deciduous forest that are on the edges of streams and the Niobrara river. Just above these valleys the ground becomes much dryer and allows for a perfect location for eastern red cedar to grow. Since the sample size was so low for the northern long-eared bat it was only really represented by these types of landscapes it is clear why eastern red cedar was predicted to influence their activity. Had the random selection procedure allowed for more sites in other parts of the state that had good northern long-eared habitat then the results would most likely be different.

Conclusions

An important thing to note is how poorly many of the models appeared to perform. This could be caused by a number of issues. The first and in my opinion the most important is the size of scales used in this analysis. It is my impression that the chosen buffers were much to large and that for example northern long-eared bats activity is much more heavily influenced by finer scale variables. It is also possible that northern long-eared bat activity is not heavily impacted by the variables chosen for analysis in this study. Further investigation of fine scale variables such as tree composition of the patches they are found in or other structural variables such as the size of corridors or the structure of the understory may be more influential. The beauty of the NE NABat program is that the extended time frame of investigation can lend helpful insight into these questions.

Although many of the models developed in this study did not perform particularly well the sheer amount of data collected in this study through the NABat framework opens the door to a lot of possibilities in the future. For instance, due to the inclusion of volunteers more specific site measurements could be included in future analyses if established structure were created on landowner’s properties to have the detector placed in the exact same location each year. Currently I have relied on the accuracy of GPS devices to place detectors however if a sleeve or mount was established for each location then detectors would always be in the exact same location. This would allow a coordinator to survey each location in detail and look at more site specific measurements over time.

The general conclusions that can be taken from this study are that the bats of Nebraska have a positive relationship with higher amounts of generally taller trees, smaller distances to accessible water, and lower areas of cropland and grassland. This is not surprising however it does show the importance of managing forest landscapes to the best of our ability. Forest is clearly an important factor in the activity of bats with grassland and cropland having the opposite relationship. Through these results I would recommend an investment in the maintenance of the forests of Nebraska and would encourage future bat research to look into the possible benefits of increases to tree density on the Nebraska landscape. This could be in the form of native tree species shelter belts or programs similar to CRP projects that have the end goal of a forest. This study is a good example of preliminary work on what influences bat activity on the Nebraska landscape but there is a lot of room for improvement and exploration in future investigations.

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TABLES AND FIGURES

Table 2.1. Table of the land classifications used in site selection for stationary deployments in NE NABat. NE NABat land classifications were determined by simplifying the values found in Rain Water Basin Joint Venture GIS layers.

Nebraska NABat Land Classifications	Rain Water Basin Joint Venture
Cropland	38 Cropland
	201 Alfalfa
	202 Corn
	203 Fallow
	206 Sorghum
	208 Sunflowers
	209 Wheat
	211 Crop Other
Grassland	71 Mixed Grass
	73 Sandhills Grassland
	75 Short Grass
	77 Tall Grass
	87 Sand Sage
	31 CRP - Grasses
Wetland	12 Playas
	13 Sandhill Wetlands
	14 Rainwater Basins
	15 Other Wetlands
	121 Farmed - Wetlands
	122 Grassland/Buffered - Wetlands
	141 RWB Farmed - Wetlands
	142 RWB Early Successional - Wetlands
	143 RWB Late Successional - Wetlands
	152 Emergent Marsh
	153 Saline
Riparian	33 CRP - Trees Riparian
	241 Riparian Canopy
	242 Exotic Riparian Shrubland
	243 Native Riparian Shrubland
	244 River Channel
Developed	46 Urban/Suburban
	42 Rural Developed
Upland	61 Forest/Woodland (Upland)
	32 CRP - Trees Upland
Pine	63 Ponderosa Pine
	60 Many Trees, Little Grassy Understory
	69 Few Trees, Grassy Understory
Red Cedar	59 Eastern Red Cedar
	66 Juniper
Sparse	51 Badlands

Table 2.2. Variables used in models with descriptions and sources explained.

Category	Model Code	Name	Variable Description
Site Measurements	Latitude + Longitude	Latitude + Longitude	GPS location of each stationary deployment.
	CANOPY	Canopy Closure	Canopy closure recored at 5 points around each stationary detector. Points include one above the detector and 4 points 30m away from the detector to form a square.
	WATER	Water Access	Value between 0 and 3 to determine if water was present within 30m of the detector at the time it was deployed or removed from the field. 0 represents no water present, 1 water present but not accessible to bats, 2 water is partially accessible by bats, 3 water is easily accessible by bats
	Noise_1	Noise Files	Rate of noise files per recording time during each stationary deployment. Value was transformed to a log(+1).
	CLUTTER	Clutter Score	Clutter score determined by the distance to clutter in each direction in a 3-dimensional box around each stationary detector. Clutter was determined to be objects within the space between 0 and >10m from the detector.
Landscape Measurements from GIS Layers	cedar_500 cedar_1.5k cedar_5k	Eastern Redcedar Area	Based on three buffers, 500m, 1.5km, and 5km in diameter around a stationary detector, the number of 30m by 30m raster cells were totaled for the classification of Eastern redcedar. Data used was generated by the Rainwater Basin Joint Venture GIS layers
	grassland_500 grassland_1.5k grassland_5k	Grassland Area	Based on three buffers, 500m, 1.5km, and 5km in diameter around a stationary detector, the number of 30m by 30m raster cells were totaled for the classification of grassland. Data used was generated by the Rainwater Basin Joint Venture GIS layers

crop_500 crop_1.5k crop_5k	Cropland Area	Based on three buffers, 500m, 1.5km, and 5km in diameter around a stationary detector, the number of 30m by 30m raster cells were totaled for the classification of cropland. Data used was generated by the Rainwater Basin Joint Venture GIS layers
Water_dist	Distance to Water	Approximate distance from each stationary deployment to the nearest raster cell with the classification water. Data used was generated by the Rainwater Basin Joint Venture GIS layers
all.trees_500 all.trees_1.5k all.trees_5k	All Trees Area	Based on three buffers, 500m, 1.5km, and 5km in diameter around a stationary detector, the number of 30m by 30m raster cells were totaled for the classification of trees. Data used was generated by the Rainwater Basin Joint Venture GIS layers
Height_500 Height_1.5k Height_5k	Average Tree Height and Tree Presence	Based on three buffers, 500m, 1.5km, and 5km in diameter around a stationary detector, the average was taken for tree height found within. Values ranged from 0 to 15 meters in height and were defined by 30m by 30m raster cells. Since values of 0 were included in the calculation this variable also reflects tree presence. Data for this variable was generated by the USGS in their LANDFIRE GIS tree height layers.

Table 2.3. Equations for all of the models used in this study.

Model Name	Scale	Variables
M1	Site	Latitude + Longitude
M2	Site	Canopy Closure + Water Access + Latitude + Longitude
M3	Site	Noise + Clutter
M4	Site	Water Access
M5	Site	Canopy Closure
M6	Site	Clutter
M7	Site	Noise
M8	Site	Water Access + Canopy Closure
M9	Site	Noise + Water Access + Canopy Closure
Global	Site	All Site Variables Combined
M1	500m, 1.5k, 5k	Eastern Redcedar Area + Grassland Area + Cropland Area
M2	500m, 1.5k, 5k	Eastern Redcedar Area + Grassland Area + Cropland Area + Distance to Water
M3	500m, 1.5k, 5k	Average Tree Height and Tree Pressence
M4	500m, 1.5k, 5k	All Trees Area
M5	500m, 1.5k, 5k	Average Tree Height and Tree Pressence + All Trees Area
M6	500m, 1.5k, 5k	Average Tree Height and Tree Pressence + Distance to Water
M7	500m, 1.5k, 5k	All Trees Area + Distance to Water
M8	500m, 1.5k, 5k	Grassland Area + Cropland Area + Average Tree Height and Tree Pressence + Distance to Water
M9	500m, 1.5k, 5k	Grassland Area + Cropland Area + All Trees Area + Distance to Water
Global	500m, 1.5k, 5k	All Landscape Variables Combined

Table 2.4. big brown bat (Eptesicus fuscus) scale based AIC tables.

Big Brown Bat - Site

Model	AIC	k	Deltas	weights	Cumulative Weight
m2.site	515.59	6	0	0.537	0.54
mGLOBAL.site	515.89	8	0.300	0.462	1.00
m1.site	529.19	4	13.598	0.001	1.00
m9.site	533.69	5	18.093	0.000	1.00
m8.site	534.65	4	19.055	0.000	1.00
m4.site	541.33	3	25.732	0.000	1.00
m5.site	546.09	3	30.493	0.000	1.00
m3.site	553.55	4	37.956	0.000	1.00
m7.site	553.89	3	38.301	0.000	1.00
m6.site	554.09	3	38.498	0.000	1.00
mNULL.site	554.45	2	38.854	0.000	1.00

500 Meter Buffer

Model	AIC	k	Deltas	weights	Cumulative Weight
mGLOBAL.500	512.86	8	0	0.907	0.91
m8.500	518.96	6	6.10	0.043	0.95
m2.500	519.36	6	6.51	0.035	0.99
m1.500	522.24	5	9.39	0.008	0.99
m6.500	523.43	4	10.57	0.005	1.00
m9.500	525.34	6	12.49	0.002	1.00
m3.500	532.95	3	20.09	0.000	1.00
m5.500	534.11	4	21.25	0.000	1.00
m7.500	534.19	4	21.34	0.000	1.00
m4.500	545.88	3	33.03	0.000	1.00
mNULL.500	554.45	2	41.59	0.000	1.00

1.5 Kilometer Buffer

Model	AIC	k	Deltas	weights	Cumulative Weight
mGLOBAL.1.5k	513.77	8	0	0.894	0.89
m2.1.5k	519.77	6	6.00	0.044	0.94
m8.1.5k	519.89	6	6.12	0.042	0.98
m1.1.5k	521.94	5	8.17	0.015	1.00
m9.1.5k	524.92	6	11.15	0.003	1.00
m6.1.5k	526.91	4	13.14	0.001	1.00
m3.1.5k	537.49	3	23.72	0.000	1.00
m5.1.5k	538.08	4	24.31	0.000	1.00
m7.1.5k	538.83	4	25.06	0.000	1.00
m4.1.5k	550.09	3	36.32	0.000	1.00
mNULL.1.5k	554.45	2	40.68	0.000	1.00

5 kilometer Buffer

Model	AIC	k	Deltas	weights	Cumulative Weight
m8.5k	515.17	6	0	0.595	0.60
mGLOBAL.5k	515.97	8	0.80	0.399	0.99
m6.5k	525.62	4	10.44	0.003	1.00
m2.5k	526.96	6	11.79	0.002	1.00
m9.5k	528.19	6	13.02	0.001	1.00
m1.5k	529.76	5	14.59	0.000	1.00
m3.5k	534.20	3	19.02	0.000	1.00
m5.5k	536.18	4	21.01	0.000	1.00
m7.5k	539.27	4	24.10	0.000	1.00
m4.5k	548.83	3	33.65	0.000	1.00
mNULL.5k	554.45	2	39.27	0.000	1.00

Table 2.5. Final model selection of top scale-based models for the big brown bat (Eptesicus fuscus).

Model	AIC	k	Deltas	Weights	Cumulative Weight
mGLOBAL.Final	505.430	24	0.000	0.940	0.940
500m.Global	512.855	8	7.425	0.023	0.963
1.5k.Global	513.771	8	8.341	0.015	0.977
5k.m8	515.173	6	9.744	0.007	0.984
Site.m2	515.593	6	10.163	0.006	0.990
Site.Global	515.893	8	10.463	0.005	0.995
5k.Global	515.974	8	10.544	0.005	1.000
mNULL.Final	554.448	2	49.018	0.000	1.000

Table 2.6. Coefficients associated with variables of the top final model for big brown bats (Eptesicus fuscus). Overall global model which includes every variable used in this study.

Variable	Estimate	Std. Error	df	t value	Pr(>|t|)
(Intercept)	-3.795	5.517	142.572	-0.688	0.493
WATER	0.066	0.039	230.180	1.694	0.092
CANOPY	0.022	0.014	218.390	1.584	0.115
CLUTTER	0.010	0.013	208.627	0.806	0.421
Noise_1	0.031	0.023	167.434	1.342	0.181
Latitude	0.256	0.075	136.423	3.420	0.001
Longitude	0.062	0.045	138.648	1.386	0.168
cedar_500	-0.008	0.011	158.783	-0.704	0.483
crop_500	0.000	0.003	137.195	-0.038	0.969
grassland_500	0.001	0.003	134.774	0.310	0.757
all.trees_500	0.002	0.005	149.939	0.461	0.646
Height_500	0.002	0.006	135.670	0.334	0.739
cedar_1.5k	0.001	0.002	150.197	0.603	0.548
crop_1.5k	-0.001	0.001	137.747	-2.054	0.042
grassland_1.5k	-0.001	0.001	132.823	-1.395	0.165
all.trees_1.5k	-0.001	0.001	137.160	-0.860	0.391
Height_1.5k	-0.004	0.014	139.516	-0.266	0.790
cedar_5k	0.000	0.000	136.280	-0.305	0.761
crop_5k	0.000	0.000	136.570	2.129	0.035
grassland_5k	0.000	0.000	133.713	0.594	0.554
all.trees_5k	0.000	0.000	135.317	0.491	0.624
Height_5k	0.017	0.013	140.000	1.324	0.188
Water_dist	0.000	0.000	135.469	-0.704	0.483

Table 2.7. Eastern red bat scale based AIC tables.

Eastern Red Bat - Site

Model	AIC	k	Deltas	Weights	Cumulative Weight
m2.site	399.05	6	0	0.850	0.85
mGLOBAL.site	402.52	8	3.47	0.150	1.00
m8.site	418.57	4	19.51	0.000	1.00
m9.site	420.08	5	21.03	0.000	1.00
m1.site	424.06	4	25.01	0.000	1.00
m4.site	425.13	3	26.07	0.000	1.00
m5.site	444.57	3	45.52	0.000	1.00
mNULL.site	453.61	2	54.56	0.000	1.00
m6.site	453.61	3	54.56	0.000	1.00
m7.site	455.32	3	56.27	0.000	1.00
m3.site	455.32	4	56.27	0.000	1.00

500 Meter

Model	AIC	k	Deltas	Weights	Cumulative Weight
mGLOBAL.500	423.28	8	0	0.368	0.37
m9.500	423.56	6	0.28	0.319	0.69
m7.500	425.29	4	2.02	0.134	0.82
m8.500	426.19	6	2.91	0.086	0.91
m2.500	426.89	6	3.61	0.060	0.97
m1.500	428.40	5	5.12	0.028	1.00
m4.500	433.66	3	10.38	0.002	1.00
m6.500	434.56	4	11.29	0.001	1.00
m5.500	435.60	4	12.32	0.001	1.00
m3.500	440.97	3	17.69	0.000	1.00
mNULL.500	453.61	2	30.33	0.000	1.00

1.5 Kilometer

Model	AIC	k	Deltas	Weights	Cumulative Weight
mGLOBAL.1.5k	427.69	8	0	0.523	0.52
m7.1.5k	428.99	4	1.30	0.273	0.80
m9.1.5k	430.02	6	2.33	0.163	0.96
m8.1.5k	434.41	6	6.72	0.018	0.98
m6.1.5k	436.08	4	8.39	0.008	0.99
m4.1.5k	436.60	3	8.91	0.006	0.99
m2.1.5k	437.32	6	9.63	0.004	1.00
m5.1.5k	438.47	4	10.78	0.002	1.00
m1.1.5k	439.44	5	11.75	0.001	1.00
m3.1.5k	443.25	3	15.56	0.000	1.00
mNULL.1.5k	453.61	2	25.92	0.000	1.00

5 Kilometer

Model	AIC	k	Deltas	Weights	Cumulative Weight
mGLOBAL.5k	406.48	8	0	0.977	0.98
m7.5k	414.83	4	8.35	0.015	0.99
m9.5k	416.75	6	10.27	0.006	1.00
m4.5k	419.19	3	12.71	0.002	1.00
m5.5k	421.17	4	14.69	0.001	1.00
m8.5k	436.23	6	29.75	0.000	1.00
m6.5k	437.26	4	30.78	0.000	1.00
m2.5k	440.04	6	33.56	0.000	1.00
m1.5k	442.09	5	35.61	0.000	1.00
m3.5k	443.18	3	36.70	0.000	1.00
mNULL.5k	453.61	2	47.13	0.000	1.00

Table 2.8. Final model selection of top scale-based models for the Eastern red bat.

Model	AIC	k	Deltas	Weights	Cumulative Weight
mGLOBAL.Final	390.968	24	0.000	0.982	0.982
Site.m2	399.052	6	8.085	0.017	1.000
5k.Global	406.480	8	15.512	0.000	1.000
500m.Global	423.278	8	32.310	0.000	1.000
500m.m9	423.559	6	32.592	0.000	1.000
1.5k.Global	427.689	8	36.722	0.000	1.000
1.5k.m7	428.987	4	38.019	0.000	1.000
mNUL.Final	453.612	2	62.644	0.000	1.000

Table 2.9. Coefficients associated with variables of the top final model for the Eastern red bats. Overall global model which includes every variable used in this study.

Variable	Estimate	Std. Error	df	t value	Pr(>|t|)
(Intercept)	12.55599	3.75889	135.5874	3.3403	0.0011
WATER	0.09730	0.02897	190.1467	3.3590	0.0009
CANOPY	-0.00151	0.01118	242.6599	-0.1351	0.8927
CLUTTER	-0.00329	0.01077	238.4858	-0.3058	0.7600
Noise_1	-0.01648	0.01997	201.6984	-0.8252	0.4102
Latitude	-0.12028	0.05059	129.8512	-2.3777	0.0189
Longitude	0.07302	0.03032	132.2496	2.4079	0.0174
cedar_500	-0.00108	0.00798	163.6914	-0.1350	0.8928
crop_500	-0.00448	0.00180	130.8604	-2.4910	0.0140
grassland_500	-0.00290	0.00193	127.8690	-1.5027	0.1354
all.trees_500	0.00442	0.00326	145.7914	1.3548	0.1776
Height_500	-0.00458	0.00392	129.3950	-1.1692	0.2445
cedar_1.5k	0.00082	0.00118	152.9221	0.6967	0.4871
crop_1.5k	0.00054	0.00036	133.4925	1.4878	0.1392
grassland_1.5k	0.00013	0.00038	126.4409	0.3431	0.7321
all.trees_1.5k	-0.00141	0.00080	131.5547	-1.7567	0.0813
Height_1.5k	0.01504	0.00964	136.6029	1.5593	0.1212
cedar_5k	-0.00021	0.00009	130.1627	-2.1812	0.0310
crop_5k	-0.00003	0.00003	131.6214	-0.8720	0.3848
grassland_5k	0.00001	0.00003	127.4491	0.4499	0.6536
all.trees_5k	0.00022	0.00008	129.5294	2.7834	0.0062
Height_5k	-0.01230	0.00890	138.0991	-1.3813	0.1694
Water_dist	-0.00001	0.00008	129.9051	-0.0730	0.9419

Table 2.10. Hoary bat scale based AIC tables.

Hoary Bat -Site

Model	AIC	k	Deltas	Weights	Cumulative Weight
m2.site	469.56	6	0	0.849	0.85
mGLOBAL.site	473.02	8	3.46	0.151	1.00
m1.site	486.99	4	17.42	0.000	1.00
m8.site	496.45	4	26.89	0.000	1.00
m9.site	498.06	5	28.50	0.000	1.00
m4.site	499.26	3	29.70	0.000	1.00
m5.site	515.56	3	46.00	0.000	1.00
mNULL.site	520.55	2	50.99	0.000	1.00
m6.site	522.25	3	52.69	0.000	1.00
m7.site	522.31	3	52.75	0.000	1.00
m3.site	524.02	4	54.46	0.000	1.00

500m Buffer

Model	AIC	k	Deltas	Weights	Cumulative Weight
m8.500	498.78	6	0	0.308	0.31
m1.500	499.21	5	0.43	0.248	0.56
m9.500	499.66	6	0.88	0.198	0.75
m2.500	499.82	6	1.05	0.182	0.94
mGLOBAL.500	502.61	8	3.83	0.045	0.98
m7.500	506.11	4	7.34	0.008	0.99
m6.500	506.55	4	7.77	0.006	1.00
m3.500	509.06	3	10.28	0.002	1.00
m4.500	509.84	3	11.06	0.001	1.00
m5.500	509.86	4	11.08	0.001	1.00
mNULL.500	520.55	2	21.77	0.000	1.00

1.5 Kilometer Buffer

Model	AIC	k	Deltas	Weights	Cumulative Weight
m8.1.5k	498.49	6	0	0.444	0.44
m1.1.5k	500.45	5	1.97	0.166	0.61
m9.1.5k	501.24	6	2.75	0.112	0.72
m2.1.5k	501.33	6	2.84	0.107	0.83
mGLOBAL.1.5k	501.84	8	3.35	0.083	0.91
m6.1.5k	502.49	4	4.00	0.060	0.97
m3.1.5k	505.37	3	6.88	0.014	0.99
m7.1.5k	507.03	4	8.54	0.006	0.99
m5.1.5k	507.04	4	8.55	0.006	1.00
m4.1.5k	510.36	3	11.87	0.001	1.00
mNULL.1.5k	520.55	2	22.06	0.000	1.00

5 Kilometer

Model	AIC	k	Deltas	Weights	Cumulative Weight
m8.5k	494.93	6	0	0.310	0.31
mGLOBAL.5k	495.96	8	1.03	0.185	0.50
m5.5k	495.99	4	1.06	0.182	0.68
m9.5k	496.38	6	1.45	0.150	0.83
m7.5k	498.42	4	3.49	0.054	0.88
m6.5k	498.46	4	3.52	0.053	0.94
m4.5k	499.69	3	4.76	0.029	0.96
m3.5k	500.02	3	5.08	0.024	0.99
m1.5k	502.52	5	7.59	0.007	1.00
m2.5k	503.46	6	8.53	0.004	1.00
mNULL.5k	520.55	2	25.62	0.000	1.00

Table 2.11. Final model selection of top scale-based models for the hoary bat.

Model	AIC	k	Deltas	Weights	Cumulative Weight
Site.m2	469.562	6	0	0.836	0.836
mGLOBAL.Final	472.815	24	3.254	0.164	1
5k.m8	494.932	6	25.37	0	1
5k.Global	495.962	8	26.4	0	1
5k.m5	495.993	4	26.431	0	1
5k.m9	496.377	6	26.815	0	1
1.5k.m8	498.49	6	28.928	0	1
500m.m8	498.777	6	29.215	0	1
500m.m1	499.206	5	29.644	0	1
500m.m9	499.659	6	30.098	0	1
500m.m2	499.823	6	30.262	0	1
1.5k.m1	500.455	5	30.893	0	1
mNULL.Final	520.551	2	50.989	0	1

Table 2.12. Coefficients associated with variables of the top final model for the hoary bat. Site model 2 was the final model selected.

Variable	Estimate	Std. Error	df	t value	Pr(>|t|)
(Intercept)	-1.113	3.369	136.916	-0.330	0.741668
CANOPY	0.020	0.011	241.283	1.853	0.065173
WATER	0.146	0.035	216.940	4.184	0.000042
Latitude	0.338	0.068	131.136	4.978	0.000002
Longitude	0.124	0.028	138.089	4.424	0.000020

Table 2.13. Silver-haired bat scale based AIC tables.

Silver-haired Bat - Site

Model	AIC	k	Deltas	Weights	Cumulative Weight
mGLOBAL.site	387.54	8	0	0.962	0.96
m2.site	394.19	6	6.65	0.035	1.00
m1.site	399.30	4	11.75	0.003	1.00
m9.site	402.19	5	14.64	0.001	1.00
m4.site	408.20	3	20.66	0.000	1.00
m7.site	408.88	3	21.34	0.000	1.00
m3.site	410.03	4	22.49	0.000	1.00
m8.site	410.19	4	22.65	0.000	1.00
mNULL.site	418.32	2	30.78	0.000	1.00
m6.site	419.48	3	31.94	0.000	1.00
m5.site	420.20	3	32.66	0.000	1.00

500 Meter

Model	AIC	k	Deltas	Weights	Cumulative Weight
m2.500	387.33	6	0	0.388	0.39
m1.500	387.40	5	0.07	0.375	0.76
mGLOBAL.500	388.88	8	1.54	0.180	0.94
m9.500	392.02	6	4.69	0.037	0.98
m8.500	393.33	6	5.99	0.019	1.00
m6.500	403.16	4	15.83	0.000	1.00
m7.500	407.19	4	19.85	0.000	1.00
m3.500	408.98	3	21.64	0.000	1.00
m5.500	410.82	4	23.49	0.000	1.00
m4.500	414.45	3	27.12	0.000	1.00
mNULL.500	418.32	2	30.99	0.000	1.00

1.5 Kilometer Buffer

Model	AIC	k	Deltas	Weights	Cumulative Weight
m1.1.5k	386.82	5	0	0.388	0.39
m2.1.5k	387.08	6	0.26	0.341	0.73
mGLOBAL.1.5k	387.74	8	0.92	0.246	0.98
m8.1.5k	393.45	6	6.63	0.014	0.99
m9.1.5k	394.15	6	7.33	0.010	1.00
m6.1.5k	399.76	4	12.94	0.001	1.00
m3.1.5k	406.05	3	19.23	0.000	1.00
m7.1.5k	406.63	4	19.81	0.000	1.00
m5.1.5k	407.92	4	21.10	0.000	1.00
m4.1.5k	413.51	3	26.69	0.000	1.00
mNULL.1.5k	418.32	2	31.50	0.000	1.00

5 Kilometer

Model	AIC	k	Deltas	Weights	Cumulative Weight
mGLOBAL.5k	384.04	8	0	0.941	0.94
m8.5k	390.11	6	6.08	0.045	0.99
m6.5k	394.17	4	10.13	0.006	0.99
m2.5k	395.44	6	11.40	0.003	1.00
m1.5k	395.62	5	11.58	0.003	1.00
m9.5k	398.23	6	14.20	0.001	1.00
m3.5k	398.75	3	14.71	0.001	1.00
m5.5k	400.05	4	16.01	0.000	1.00
m7.5k	403.45	4	19.42	0.000	1.00
m4.5k	408.42	3	24.38	0.000	1.00
mNULL.5k	418.32	2	34.29	0.000	1.00

Table 2.14. Final model selection of top scale-based models for the silver-haired bat.

Model	AIC	k	Deltas	Weights	Cumulative Weight
mGLOBAL.Final	366.19	24	0	0.9997	0.9997
5k.Global	384.04	8	17.85	0.0001	0.9998
1.5k.m1	386.82	5	20.63	0	0.9999
1.5k.m2	387.08	6	20.89	0	0.9999
500m.m2	387.33	6	21.14	0	0.9999
500m.m1	387.4	5	21.21	0	0.9999
Site.Global	387.54	8	21.36	0	1
1.5k.Global	387.74	8	21.55	0	1
500m.Global	388.88	8	22.69	0	1
mNULL.Final	418.32	2	52.13	0	1

Table 2.15. Coefficients associated with variables of the top final model for the silver-haired bat. Overall global model which includes every variable used in this study.

Variable	Estimate	Std. Error	df	t value	Pr(>|t|)
(Intercept)	-5.989	4.262	141.192	-1.405	0.162
WATER	0.035	0.03	235.271	1.169	0.243
CANOPY	-0.002	0.01	211.811	-0.151	0.88
CLUTTER	0.008	0.01	201.496	0.879	0.38
Noise_1	0.053	0.017	160.917	3.157	0.002
Latitude	0.21	0.058	135.075	3.626	0
Longitude	0.027	0.035	137.244	0.774	0.44
cedar_500	0.009	0.009	155.778	0.999	0.319
crop_500	-0.003	0.002	135.846	-1.219	0.225
grassland_500	0	0.002	133.514	-0.209	0.835
all.trees_500	-0.003	0.004	148.116	-0.904	0.367
Height_500	0.001	0.004	134.32	0.125	0.901
cedar_1.5k	-0.001	0.001	147.531	-0.565	0.573
crop_1.5k	-0.001	0	136.071	-2.066	0.041
grassland_1.5k	-0.001	0	131.502	-1.734	0.085
all.trees_1.5k	0	0.001	135.72	-0.065	0.948
Height_1.5k	-0.008	0.011	137.691	-0.733	0.465
cedar_5k	0	0	134.858	-2.344	0.021
crop_5k	0	0	135.03	2.812	0.006
grassland_5k	0	0	132.372	1.72	0.088
all.trees_5k	0	0	133.899	2.088	0.039
Height_5k	0.014	0.01	138.031	1.413	0.16
Water_dist	0	0	134.047	0.132	0.895

Table 2.16. Northern long-eared bat scale based AIC tables.

Northern Long-eared Bat - Site

Model	AIC	k	Deltas	Weights	Cumulative Weight
m2.site	-97.75	6	0	0.583	0.58
mGLOBAL.site	-97.06	8	0.69	0.412	1.00
m5.site	-87.20	3	10.55	0.003	1.00
m8.site	-85.32	4	12.43	0.001	1.00
m9.site	-83.83	5	13.92	0.001	1.00
m1.site	-81.42	4	16.33	0.000	1.00
m6.site	-73.14	3	24.61	0.000	1.00
mNULL.site	-71.84	2	25.91	0.000	1.00
m3.site	-71.19	4	26.56	0.000	1.00
m7.site	-69.91	3	27.84	0.000	1.00
m4.site	-69.85	3	27.90	0.000	1.00

500 Meter Buffer

Model	AIC	k	Deltas	Weights	Cumulative Weight
mGLOBAL.500	-125.60	8	0	0.977	0.98
m1.500	-117.12	5	8.49	0.014	0.99
m2.500	-115.16	6	10.45	0.005	1.00
m4.500	-113.05	3	12.55	0.002	1.00
m5.500	-111.55	4	14.06	0.001	1.00
m7.500	-111.35	4	14.25	0.001	1.00
m9.500	-108.60	6	17.00	0.000	1.00
m3.500	-101.46	3	24.14	0.000	1.00
m8.500	-100.04	6	25.57	0.000	1.00
m6.500	-99.92	4	25.68	0.000	1.00
mNULL.500	-71.84	2	53.77	0.000	1.00

1.5 Kilometer Buffer

Model	AIC	k	Deltas	Weights	Cumulative Weight
mGLOBAL.1.5k	-120.76	8	0	0.668	0.67
m1.1.5k	-118.68	5	2.07	0.237	0.91
m2.1.5k	-116.84	6	3.92	0.094	1.00
m4.1.5k	-105.31	3	15.44	0.000	1.00
m7.1.5k	-103.53	4	17.23	0.000	1.00
m5.1.5k	-103.36	4	17.40	0.000	1.00
m9.1.5k	-101.22	6	19.53	0.000	1.00
m3.1.5k	-90.70	3	30.05	0.000	1.00
m6.1.5k	-88.87	4	31.89	0.000	1.00
m8.1.5k	-88.64	6	32.12	0.000	1.00
mNULL.1.5k	-71.84	2	48.92	0.000	1.00

5 Kilometer Buffer

Model	AIC	k	Deltas	Weights	Cumulative Weight
m1.5k	-96.09	5	0	0.620	0.62
m2.5k	-94.10	6	1.99	0.229	0.85
mGLOBAL.5k	-93.24	8	2.85	0.149	1.00
m9.5k	-82.31	6	13.78	0.001	1.00
m4.5k	-81.68	3	14.41	0.000	1.00
m7.5k	-80.04	4	16.06	0.000	1.00
m5.5k	-79.68	4	16.41	0.000	1.00
m8.5k	-75.65	6	20.45	0.000	1.00
m3.5k	-74.35	3	21.75	0.000	1.00
m6.5k	-72.58	4	23.52	0.000	1.00
mNULL.5k	-71.84	2	24.26	0.000	1.00

Table 2.17. Final model selection of top scale-based models for the northern long-eared bat.

Model	AIC	k	Deltas	Weights	Cumulative Weight
500m.Global	-125.60	8	0	0.89292	0.89292
1.5k.Global	-120.76	8	4.8477	0.07909	0.97201
mGLOBAL.Final	-118.68	24	6.92542	0.02799	1
Site.m2	-97.75	6	27.85354	0	1
Site.Global	-97.06	8	28.54768	0	1
5k.m1	-96.09	5	29.50908	0	1
5k.m2	-94.10	6	31.50048	0	1
mNULL.Final	-71.84	2	53.76833	0	1

Table 2.18. Coefficients associated with variables of the top final model for the northern long-eared bat. The 500m Global model was the final model selected.

Variable	Estimate	Std. Error	df	t value	Pr(>|t|)
(Intercept)	0.02108	0.05984	103.68	0.35	0.72538
cedar_500	0.01741	0.00365	100.41	4.78	0.00001
crop_500	-0.00025	0.0004	103.10	-0.63	0.53049
grassland_500	-0.00024	0.0004	103.21	-0.61	0.54201
all.trees_500	0.00045	0.00078	107.36	0.57	0.56701
Height_500	0.00162	0.0008	111.69	2.02	0.04554
Water_dist	-0.00001	0.00005	102.86	-0.25	0.80655

Table 2.19. Evening bat scale based AIC tables.

Evening Bat - Site

Model	AIC	k	Deltas	Weights	Cumulative Weight
mGLOBAL.site	347.12	8	0	0.687	0.69
m9.site	348.73	5	1.61	0.307	0.99
m2.site	357.25	6	10.13	0.004	1.00
m8.site	360.72	4	13.60	0.001	1.00
m4.site	361.38	3	14.26	0.001	1.00
m7.site	363.67	3	16.55	0.000	1.00
m3.site	364.24	4	17.12	0.000	1.00
m1.site	367.65	4	20.53	0.000	1.00
m5.site	372.55	3	25.43	0.000	1.00
mNULL.site	374.51	2	27.39	0.000	1.00
m6.site	375.24	3	28.12	0.000	1.00

500 Meter Buffer

Model	AIC	k	Deltas	Weights	Cumulative Weight
m1.500	359.07	5	0	0.276	0.28
mGLOBAL.500	359.79	8	0.72	0.192	0.47
m2.500	359.93	6	0.86	0.180	0.65
m8.500	360.16	6	1.09	0.160	0.81
m9.500	361.28	6	2.21	0.091	0.90
m6.500	362.67	4	3.60	0.046	0.95
m3.500	363.37	3	4.30	0.032	0.98
m5.500	364.52	4	5.45	0.018	1.00
m7.500	368.14	4	9.07	0.003	1.00
m4.500	369.86	3	10.79	0.001	1.00
mNULL.500	374.51	2	15.44	0.000	1.00

1.5 Kilometer Buffer

Model	AIC	k	Deltas	Weights	Cumulative Weight
mGLOBAL.1.5k	360.29	8	0	0.344	0.34
m5.1.5k	361.27	4	0.98	0.211	0.55
m6.1.5k	362.44	4	2.15	0.117	0.67
m8.1.5k	362.80	6	2.51	0.098	0.77
m1.1.5k	363.11	5	2.82	0.084	0.85
m3.1.5k	363.66	3	3.37	0.064	0.92
m2.1.5k	364.03	6	3.74	0.053	0.97
m9.1.5k	365.48	6	5.19	0.026	1.00
m7.1.5k	370.14	4	9.85	0.002	1.00
m4.1.5k	371.83	3	11.54	0.001	1.00
mNULL.1.5k	374.51	2	14.22	0.000	1.00

5 Kilometer Buffer

Model	AIC	k	Deltas	Weights	Cumulative Weight
m5.5k	353.72	4	0	0.394	0.39
m3.5k	354.77	3	1.05	0.233	0.63
m6.5k	355.30	4	1.58	0.179	0.81
m8.5k	356.17	6	2.45	0.116	0.92
mGLOBAL.5k	357.05	8	3.33	0.074	1.00
m9.5k	365.55	6	11.83	0.001	1.00
m1.5k	365.84	5	12.12	0.001	1.00
m2.5k	366.93	6	13.21	0.001	1.00
m7.5k	367.39	4	13.67	0.000	1.00
m4.5k	368.14	3	14.42	0.000	1.00
mNULL.5k	374.51	2	20.79	0.000	1.00

Table 2.20. Final model selection of top scale-based models for the evening bat.

Model	AIC	k	Deltas	Weights	Cumulative Weight
Site.Global	347.12	8	0	0.63689	0.637
Site.m9	348.73	5	1.608	0.28508	0.922
mGLOBAL.Final	353.70	24	6.579	0.02373	0.946
5k.m5	353.72	4	6.598	0.02352	0.969
5k.m3	354.77	3	7.644	0.01394	0.983
5k.m6	355.30	4	8.174	0.01069	0.994
500m.m1	359.07	5	11.951	0.00162	0.995
500m.Global	359.79	8	12.672	0.00113	0.997
500m.m2	359.93	6	12.807	0.00105	0.998
500m.m8	360.16	6	13.043	0.00094	0.999
1.5k.Global	360.29	8	13.171	0.00088	0.999
1.5k.m5	361.27	4	14.149	0.00054	1
mNULL.Final	374.51	2	27.388	0	1

Table 2.21. Coefficients associated with variables of the top final model for the northern long-eared bat. The site Global model was the final model selected.

Variable	Estimate	Std. Error	df	t value	Pr(>|t|)
(Intercept)	12.467	4.516	115.429	2.761	0.00671
CANOPY	0.021	0.010	198.692	2.042	0.04249
WATER	0.107	0.033	172.709	3.223	0.00152
Noise_1	0.091	0.024	162.316	3.829	0.00018
CLUTTER	-0.003	0.013	189.113	-0.242	0.80913
Latitude	-0.098	0.061	109.794	-1.617	0.10878
Longitude	0.087	0.040	113.485	2.168	0.03224

Table 2.22. Coefficients associated with variables of the top final model for the northern long-eared bat. The site model 9 was one of the final models selected.

Variable	Estimate	Std. Error	df	t value	Pr(>|t|)
(Intercept)	-0.117	0.100	195.526	-1.165	0.24547
Noise_1	0.092	0.024	159.504	3.811	0.0002
WATER	0.122	0.033	171.029	3.680	0.00031
CANOPY	0.021	0.010	190.203	2.104	0.03671

Figure 2.1. Map of the final 35 grid cells surveyed in 2016 and 2017. Each of these cells contains a driving transect route and between 2 and 4 established stationary detector locations.

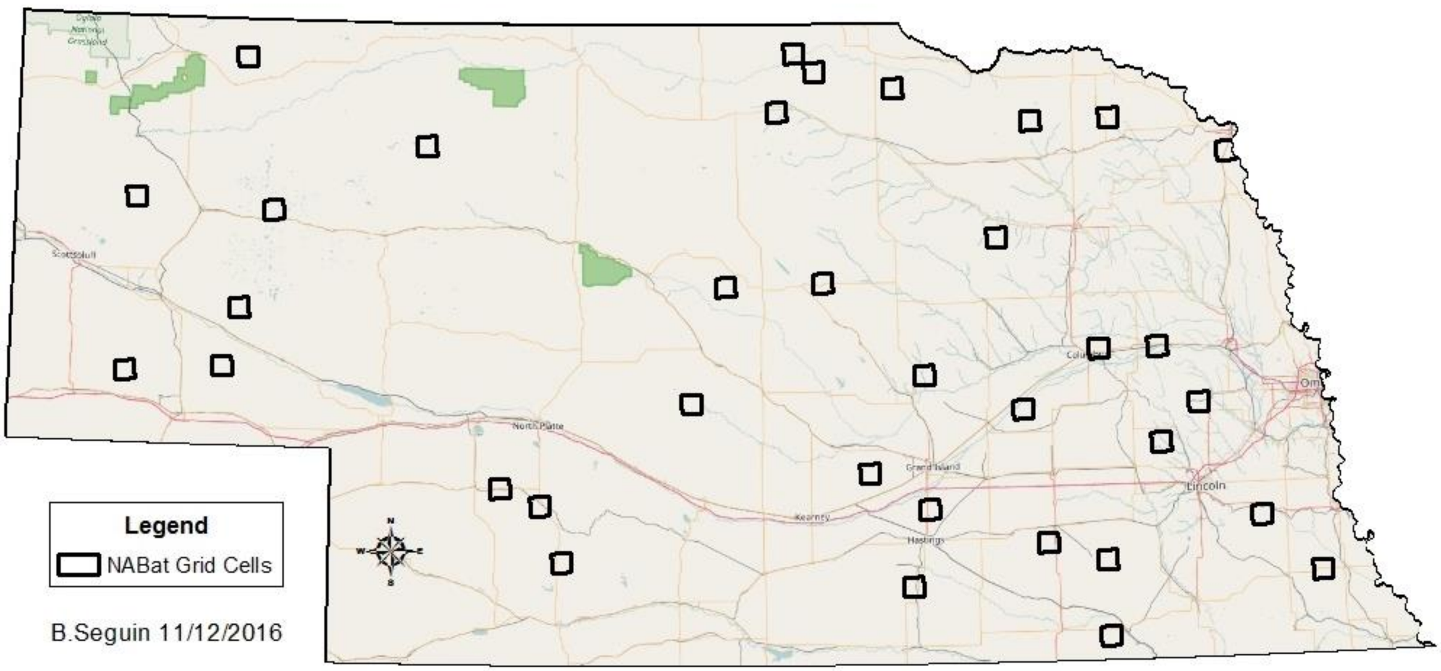


Figure 2.2. Hoary bat final model plot. Model selected was site model 2.

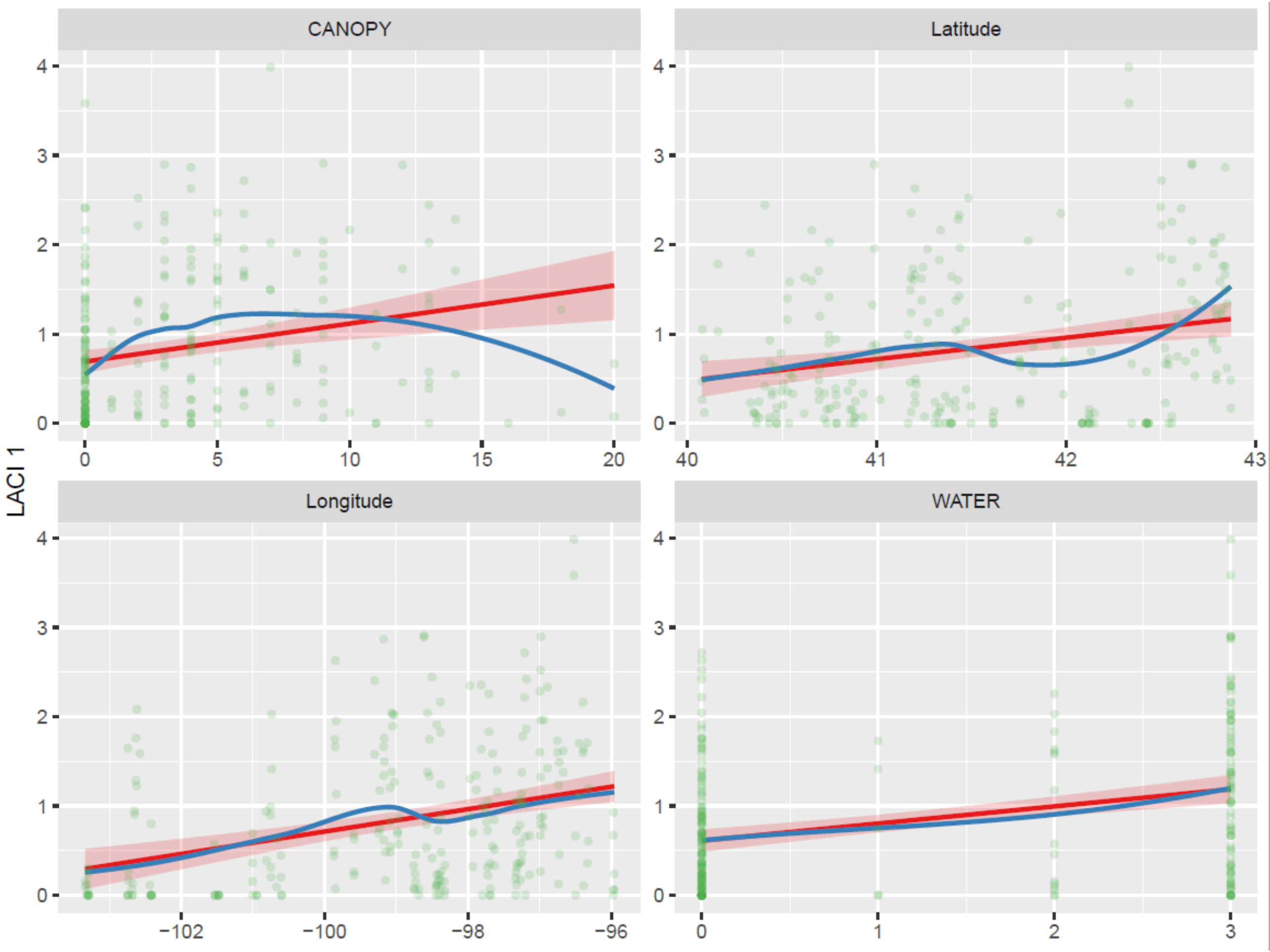


Figure 2.3. Northern long-eared bat final model plot. Model selected was the 500m Global model.

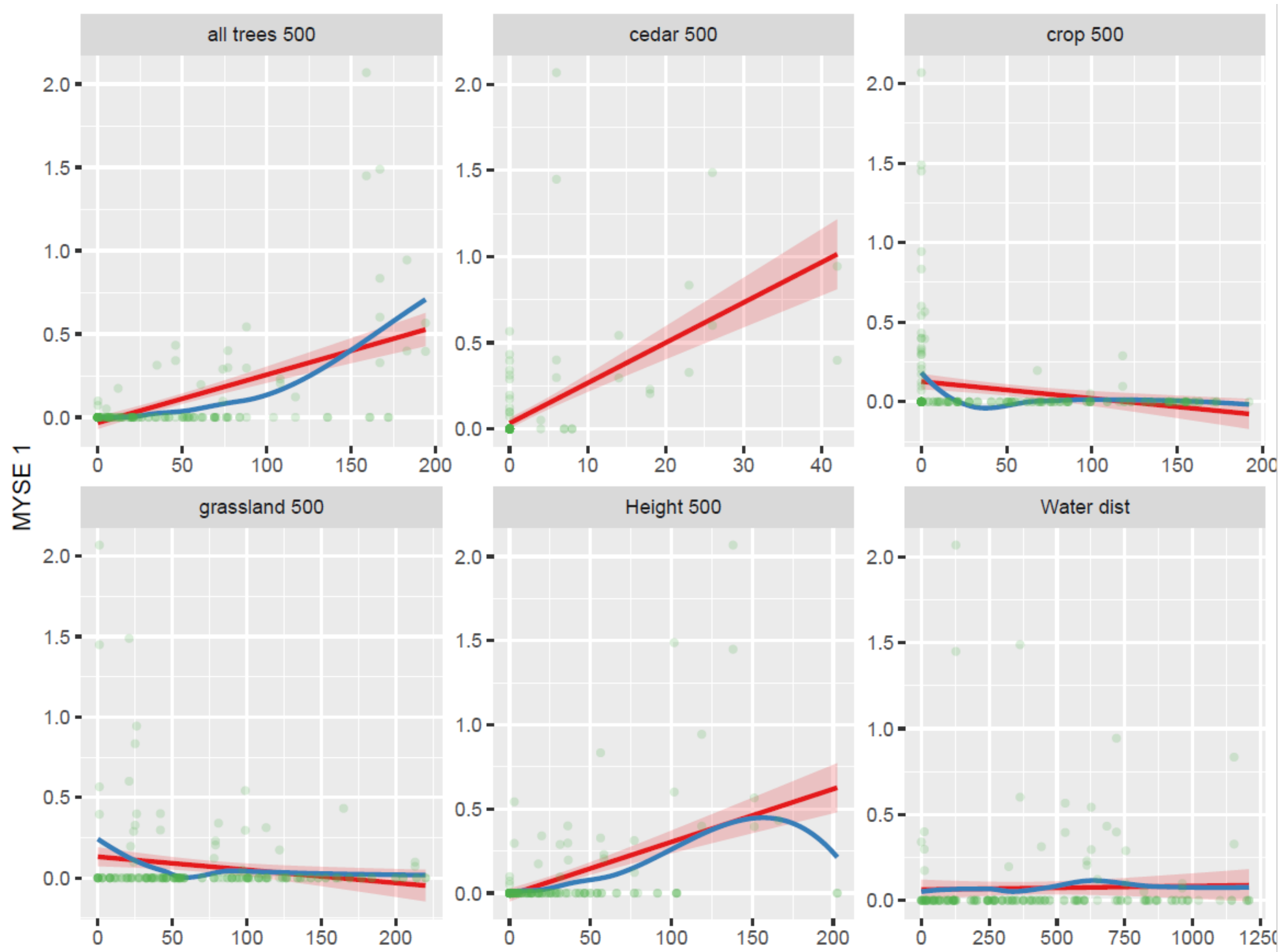


Figure 2.4. Evening bat first final model plot. This is the site Global model.

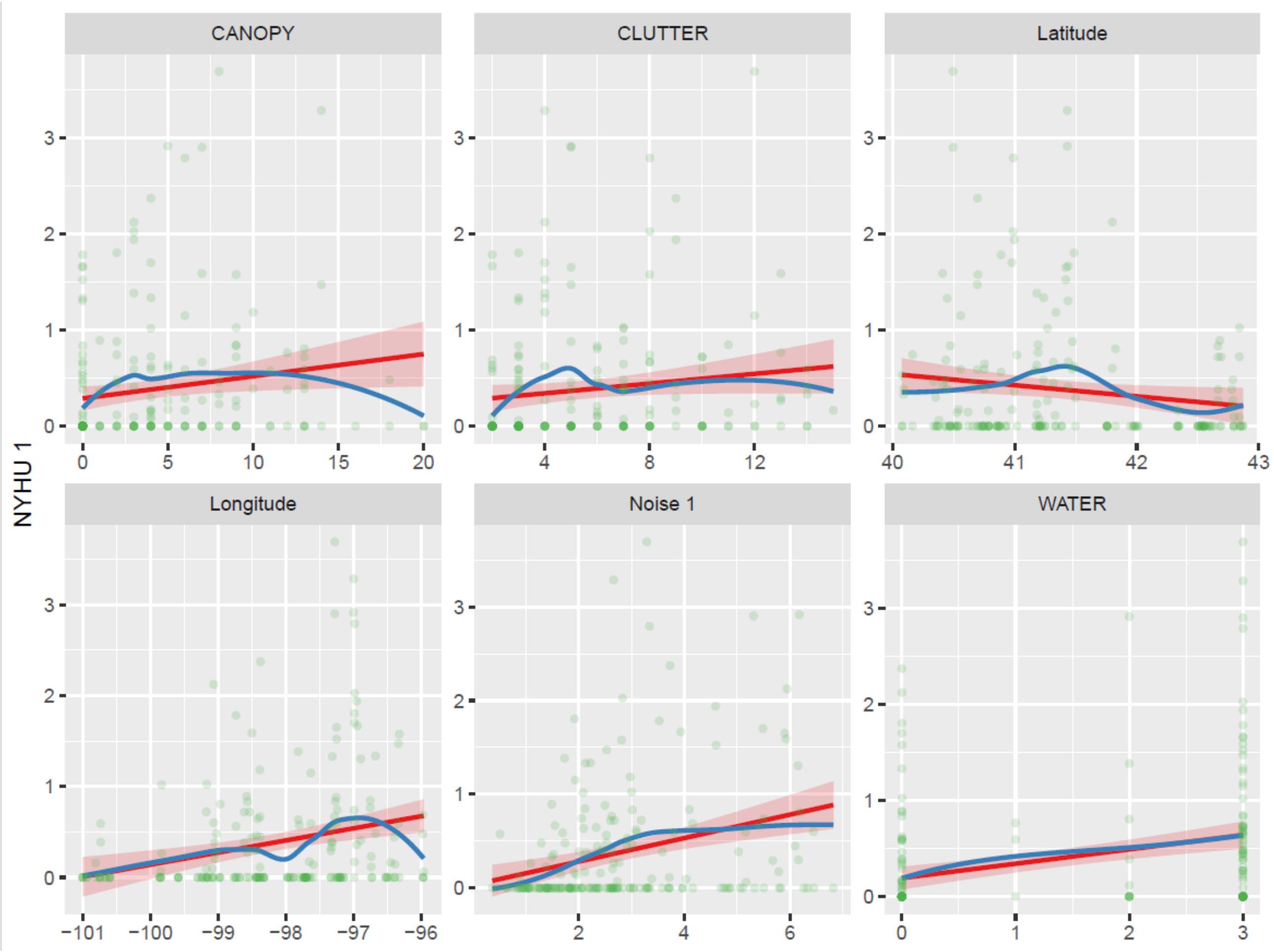
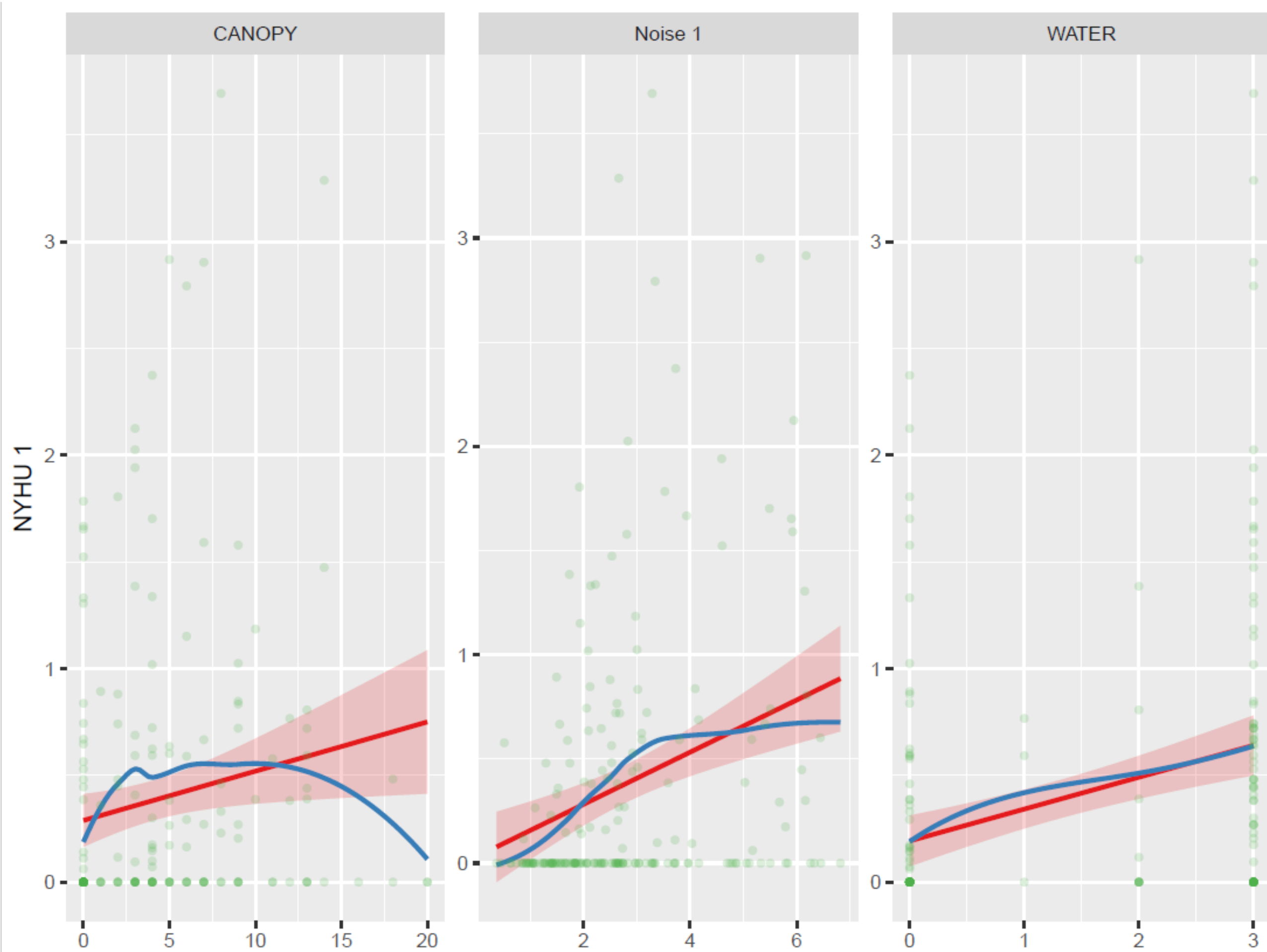


Figure 2.5. Evening bat second final model plot. This is the site model 9.



CHAPTER 3: HOW LONG DOES IT TAKE TO DETECT A DECLINE? A POWER ANALYSIS OF NEBRASKA NABAT DRIVING TRANSECTS

INTRODUCTION

Long term monitoring of plant and animal populations is often paramount to efficient and effective conservation of biodiversity. However, many studies of environmental systems follow timelines limited by graduate student program length. This can result in short term studies that are applied to long term challenges; given that slow drivers of change at global scales are frequent, solutions based on limited data may result in erroneous conclusions. In an attempt to move away from these short timelines, I implemented the North American Bat Monitoring Program throughout the state of Nebraska. The Nebraska North American Bat Monitoring Program has the potential to continue monitoring far into the future and aid in the conservation and biodiversity of bat species across the state. The program is also replicated in other states, providing for broader scale inference and potential for benefits in bat conservation across entire species ranges.

The 11 species of bat commonly found in Nebraska are insectivores and consume massive quantities of insects throughout the diverse ecosystems of Nebraska. Estimates of their economic contribution to agricultural systems globally are approximately over 3.7 billion dollar annually, so conserving their populations is likely beneficial not only to humans but the ecosystems they inhabit (Boyles et al. 2011, Maine and Boyles 2015). However, like many wildlife species in our increasingly anthropogenically influenced world, bats have suffered disturbance and habitat loss throughout the past century (Racey and Entwistle 2003, Weller et al. 2009). This disruption to their populations has occurred at an unprecedented level in the past two decades in North America with the emergence of two new threats, wind energy development and the disease white-nose syndrome (Blehert et al. 2009, Frick et al. 2010, Foley et al. 2011, Blehert 2012).

Wind energy development has increased in the past several decades and causes high levels of mortality in migratory and tree roosting bats like the silver haired bat (*Lasionycteris noctivagans*), eastern red bat *(Lasiurus borealis*), and hoary bat (*Lasiurus cinereus*) which are all common in Nebraska (Arnett et al. 2008, Arnett and Baerwald 2013, Hein and Schirmacher 2016). Some estimates have determined that 3-4 bats are killed at each wind turbine each year, which when extrapolated to the number of turbines in the country is a mortality rate that could have significant population impacts over time (Arnett et al. 2008, Hein and Schirmacher 2016). Unfortunately, unlike cave or building hibernating species that congregate in high concentrations in locations that have been monitored for decades, giving us relatively reliable population estimates, many of the migratory species are understudied and researchers have little to no idea how much wind energy is impacting them (Kunz et al. 2007).

White-nose syndrome (WNS), a disease caused by the fungus *Pseudogymnoascus destructans*, has caused catastrophic decline of cave and building hibernating bats since 2006 in the eastern portion of the U.S. (Frick et al. 2010). Since it was discovered in New York State the disease has spread across the United States and produced >70% mortality in a majority of the hibernacula that are infected with it with some species reaching 99% mortality (Frick et al. 2010, Fisher et al. 2012). These challenges mean that largescale efforts that cross state boundaries need to be implemented in order to conserve bat habitat and influence their recovery or we may be facing an extinction event in North America with potentially significant ecological and agricultural ramifications (Coleman et al. 2011).

An emerging methodology to study bat populations over time is the use of acoustic driving transects. Many studies in Europe and in the United states have used driving transects to assess population changes in bats, although many in the United States have been conducted for only a handful of years (Russ et al. 2003, Roche et al. 2011, McGowan and Hogue 2016, Braun de Torrez et al. 2017, Fisher-Phelps et al. 2017). The goal of many of these studies is to determine if declines are occurring within the bat populations of a specific region. Factors that affect species decline, such as WNS and wind energy in bats, need to be documented as early as possible in order to prevent loss of biodiversity. To avoid surprising population declines due to emerging threats it is critical that we maintain monitoring programs that can potentially warn managers of declines that are occurring and allow for evidence to support researching potential solutions.

This study was developed using the driving transect portion of NE NABat and determine its viability and effectiveness for detecting declines in Nebraska bats. In order to evaluate NE NABat transects I utilized a power analysis that would provide insight into how many years of data are required for the dataset to reveal if a population decline is occurring. I used decline scenarios outlined in the International Union of Conservation (IUCN) for Amber and Red level declines and determined a third scenario which I have called a Catastrophic decline. Through power analysis I was able to show that in a relatively short period of time NE NABat would be able to reveal if a decline was occurring in the Nebraska bat population. This is crucial in providing a justification for continuing NE NABat into the future.

METHODS

SURVEY METHODS

The methodology for data collection in this study was based on the North American Bat Monitoring Program (NABat) (Loeb et al. 2015). In NABat a web of 10 km by 10 km grids are numbered using a generalized random tessellation stratified (GRTS) survey design algorithm to establish spatially balanced random sampling locations (Stevens and Olsen 2004). Thirty-five grid cells of the NABat master sample were selected within the state of Nebraska that had >75% of their area within the state and adequate roads to establish a 25-45 km transects that could be driven safely at 32 km/h. Each transect was driven twice in the months of June and July in 2016 and 2017 within 7 days of one another and with similar weather conditions. Transects were not driven during rain, on exceptionally cold nights or when winds were consistently >20 km/h. A significant amount of effort also went into making sure that transects were driven within a week of the date they were driven the previous year in order to account for young volant individuals born that year. Each of the transect routes were placed so that they crossed or neighbored all habitat types found within the cell whenever possible.

Bat echolocation files were recorded using Anabat Walkabout full spectrum acoustic detectors from Titley Scientific. Each Walkabout was attached to an extension cable and suction cup-mounted external microphone on the roof of a vehicle. The adjustable microphone was pointed straight up for easier repeatability. The Walkabout trigger settings were set to a 15 in ZC sensitivity, and an 8 in Crest Factor Threshold, the minimum trigger frequency was 15 kHz and the maximum trigger was 220 kHz. The recording settings for Walkabouts were a ZC Division Ratio of 8, an Auto Record Window of 2000ms and a Max File Length of 15 secs. Transects were started 45 minutes after sunset and all routes were driven at 32 km/h until they were complete. Transects were driven 32 km/h because this is faster than a majority of bats can fly (Hayward and Davis 1964, Patterson and Hardin 1969), which allows for the assumption that each recording is from an individual bat. Driving transects were driven twice each field season in order to establish replicates. Data was analyzed using Kaleidoscope Pro 4 auto classification, created by Wildlife Acoustics, on the liberal setting with the default parameters. Sub-samples of recordings files were verified using defined bat species call metrics and visual classification in AnalookW (Titley Scientific).

This analysis was restricted to the 5 most frequently encountered species: big brown bat (*Eptesicus fuscus*), Eastern red bat (*Lasiurus borealis*), hoary bat (*Lasiurus cinereus*), silver-haired bat (*Lasionycteris noctivagans*), and the evening bat (*Nycticeius humeralis*). Although a handful of recordings from other species were captured along NE transects, the overall numbers for other species was low. Due to the landscape characteristics around the roads of Nebraska this is not surprising since many of the other species are interior forest or edge of forest species which is not easy to sample with Nebraska roads. Although transects have been criticized for their inability to record or document rare bat species (Braun de Torrez et al. 2017), it does not delegitimize them.

Scenarios

Two of the declines, Amber and Red, were based on the International Union of Conservation (IUCN). The Amber alert decline imposes a 25% decline over 25 years

(1.144% per year), the Red alert decline imposes a 50% decline over 25 years (2.735% per year), and the final decline rate which I have labeled a Catastrophic decline rate imposes a 75% decline over 25 years (5.394% per year). Using the expand.grid function in R the data were simulated at 9 different year intervals (4,5,6,7,8,9,10,15 and 20) for each category of decline.

Power Analysis

A simulation approach was used to test the power of the sampling design to detect decline scenarios occurring evenly across the entire state. Using the data from two years of driving transects across the state a simple mixed effects model was created for each species with adequate numbers and all the species combined. Number of calls for each species and the total were transformed using log(x + 1) in order to deal with the high number of zeros and normalize the data. Originally I attempted to use a Poisson and a Negative Binomial distribution but these models did not converge. Transect length was also log transformed since each transect is a different length depending on the cell.

$$\log(\text{species} + 1) \sim \text{Year} + \text{offset}(\log(\text{Transect Length})) + (1|\text{Grid})$$

Values were pulled from the results of the model including the random effect for each grid, the estimate and the standard deviation (Table 3.1). A new dataset was created using these values and imposing three different levels of decline. Declines were based on the scenarios discussed above. Data was simulated 1,000 times for each scenario (i.e. Big brown bat declining at 2.735% a year over 8 years). A linear regression was then done on the new generated data using the original model. Each simulation was assessed and determined to successfully detect the trend used to generate the data if the upper confidence interval was < 0 and labeled "pass" if it did. In order to calculate power, the sum of all simulations within a scenario that "pass" was divided by the total number of simulations (1,000). This resulted in a percentage that represents the power for that specific scenario.

RESULTS

SURVEY EFFORT AND NUMBER OF BAT ENCOUNTERS

In 2016 and 2017, 35 grid cells were surveyed with driving transects. Transect length ranged from 28.6 km to 49.4 km with a mean of 39.7 km and a median of 40.6 km. Including each transect being run twice each year, the total amount of road sampled was 5,553 km. In total 1,753 identifiable bat encounters were recorded along transects. Figure 3.1 shows the proportion of bat encounters for each species. The lowest number of recordings were of the evening bat (*Nycticeius humeralis*) with 180 identified or 10.3% of the total. The evening bat was only found in the southeastern quarter of the state. The hoary bat (*Lasiurus cinereus*) had 184 recordings (10.5%), silver-haired bat (*Lasionycteris noctivagans*) 365 (20.8%), Eastern red bat (*Lasiurus borealis*) 483 (27.6%), and the big brown bat (*Eptesicus fuscus*) had 541 encounters (30.9%) (Figure 3.1). Other than the evening bat all of the species analyzed in this study were found throughout the state of Nebraska although the distribution of bat encounters varied by species across the state (Figure 3.2 and Figure 3.3). These maps show the rate of calls per hour sampled over two years of sampling. Grid cells in the panhandle and the Western Sandhills of the state consistently had the lowest number of bat encounters in the state (Figure 3.2 and Figure 3.3).

Amber Scenario Power Analysis

80% power was present for each species and total bats within at least 20 years of simulated data for an Amber decline (25% decline over 25 years) scenario (Table 3.2 and Figure 3.4). The Amber scenario, as expected, took the longest amount of time to be detected by the model for each species. The big brown bat (*Eptesicus fuscus*), Eastern red bat (*Lasiurus borealis*), and silver-haired bat (*Lasionycteris noctivagans*) reached the 80% power threshold after 15 years of data (Table 3.2 and Figure 3.4). The hoary bat (*Lasiurus cinereus*), evening bat (*Nycticeius humeralis*), and all of the species combined took 20 years to reach a power of 80% or higher in the Amber decline scenario (Table 3.2 and Figure 3.4).

Red Scenario Power Analysis

Except for the evening bat, all the bat species and total bats combined reached 80% power within 10 years of data in the red decline (50% decline over 25 years) scenario (Table 3.2 and Figure 3.4). The evening bat did not reach the 80% threshold until 15 years of data was tested, although it was just below in the 10^{th} year of data (Table 3.2 and Figure 3.4). The silver-haired bat took the lowest number of years with power reaching 82% at 7 years of data (Table 3.2). The Eastern red bat and hoary bat were estimated to reach sufficient power within 9 years of data while the big brown bat and total bats took 10 years in the Red decline scenario (Table 3.2 and Figure 3.4).

Catastrophic Scenario Power Analysis

All bat species and total bats had significant power for the Catastrophic decline (75% decline over 25 years) within 7 years of data collection (Table 3.2 and Figure 3.4). The silver-haired bat also required the fewest number of years in this scenario with 94%

power obtained after 5 years of data collection (Table 3.2). The Eastern red bat and hoary bat both reached 80% power after 6 years of data collection (Table 3.2 and Figure 3.4). The big brown bat, evening bat, and total bats did not reach a power level of 80% for the Catastrophic decline scenario until 7 years of data had been collected.

DISCUSSION

Sufficient power was calculated for all 5 species and total bats combined in each of the three decline scenarios within 20 years of sampling. The Amber level decline of 25% over 25 years, or approximately 1.144% per year, understandably took the greatest number of sampling years to detect. However, with each increase of 25% in population decline over 25 years the amount of sampling years needed decreased dramatically. This analysis shows that given the data from 2016 and 2017, if monitoring is continued, population declines could be detected, on average, within about 11 years.

The number of years to detect both an Amber and Red level decline was comparable to the results from Roche et. al. (2011) though the survey design was slightly different. Roche et al. (2011) reported 14.7 and 7.6 years to reach 80% power with an Amber and Red decline within the common pipistrelle bat, 20.3 and 9.7 for the Soprano pipistrelle, and 23.5 and 12.7 for the Leisler's bat with transect lengths that were closest to the NE NABat driving transect design. The number of years required in NE NABat was very similar to these (Table 3.2). For the Amber and Red decline scenarios in this study I found that the big brown bat (*Eptesicus fuscus*) reaches 80% power at 15 and 10 years, Eastern red bat (*Lasiurus borealis*) 15 and 9 years, hoary bat (*Lasiurus cinereus*) 20 and 9 years, silver-haired bat (*Lasionycteris noctivagans*) 15 and 7 years, and the evening bat (*Nycticeius humeralis*) 20 and 15 years (Table 3.2 and Figure 3.4). This was a surprising result since the number of bat recordings was substantially lower in this study than in Roche et al. (2011).

NE NABat driving transect data showed a very low number of bat recordings per survey effort. The rate of identifiable bat recordings per minute was 0.168 across the entire state, which is lower than the numbers reported in other parts of the country. Whitby et. al. (2014) reported a bat recording rate of 1.224 per minute in Southern Illinois (Whitby et al. 2014). This can partially be explained by the difference in agricultural land prevalence between southern Illinois and Nebraska and the shift to grassland as you move from the East to the West in Nebraska. Fisher-Phelps et. al. (2017) reported 0.214 per minute in Texas in what they classified as semi-arid agricultural landscapes. Although rates of recordings in Nebraska were lower than study sites in the Eastern portion of the United States, we were still able to achieve sufficient power.

Nebraska's high winds likely had a large impact on where bats and their prey reside in the state. Technicians, volunteers, and I noticed increases in the number of bats recorded on transects when shelter belts, river corridors, or other tree associated features were crossed during transects. In Nebraska aside from shelter belts many of the dips in elevation or tree stands in the grid cells sampled did not occur along the road. These are likely havens from the wind that may have much higher levels of bat activity. This issue became more prevalent as we moved to the western portion of the state. As can be seen in the distribution maps in Figure 3.2, the densities of bat recordings were substantially lower in the western portion of the state, with some cells only having a handful of bat recordings over two years of sampling. Since grid cells were selected using the NABat GRTS value, selection of more "bat ideal" transects was not considered in this study.

The results of this power analysis come at a pivotal time due to increasing interest in wind energy facilities effects in the state of Nebraska. Three of the species that are prevalent along NE NABat transect routes, *L. borealis*, *L. cinereus*, and *L. noctivagans*, are species that are common casualties at wind turbine facilities (Hein and Schirmacher 2016). These three species represent 78% of the documented fatalities at wind turbine facilities (Hein and Schirmacher 2016). Monitoring these species over the next decade in Nebraska could provide valuable insight into the possible connections between wind turbine fatalities and population trends for the state.

Although I have shown that a trend can be determined using NE NABat driving transect data, it is possible that lower or higher numbers on transects are not the direct result of population changes. Species assemblages in the Nebraska landscape are likely to change in the wake of white-nose syndrome moving across the state which could result in lower amounts of inter species competition across the landscape. Species that are consistently recorded during Nebraska driving transects are also the same species that have not been documented to be affected by WNS. Reduction of populations of species that are susceptible to WNS may cause a reduction of competition in areas away from roads which could change the number of encounters with bats along road transects. Maintaining both the driving transects and stationary deployments of NE NABat will be the best way to decipher future changes in species assemblages throughout the Nebraska landscape.

This study has shown that the NABat design as implemented in NE can detect population declines over time. Since these transects require the least amount of training and expertise to be conducted and require significantly less time to complete than stationary deployments, they also provide a great opportunity for citizen science involvement. It is paramount that driving transect surveys continue into the future in order to inform our understanding of bat population dynamics and provide critical management information should declines occur.

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TABLES AND FIGURES

Table 3.1. Coefficients and random effects of models used to generate simulated datasets. Data was collected from driving transects conduct throughout Nebraska in the months of June and July in 2016 and 2017. The formula for each model was log(species +1) ~ Year + offset(log(Transect Length)) + (1|Grid).

All Species Combined				
	Estimate	SE	t-value	p value
Intercept	-1.69633	0.26623	-6.372	5.19E-09
Year	-0.8783	0.12642	-0.695	0.489
Random effect Grid = 1.0403				
Residual = 0.7479				

Eptesicus fuscus (Big Brown Bat)				
	Estimate	SE	t-value	p value
Intercept	-2.85263	0.20684	-13.791	<2e-16
Year	0.03016	0.09539	0.316	0.753
Random effect Grid = 0.8374				
Residual = 0.5644				

Lasiurus borealis (Eastern Red Bat)				
	Estimate	SE	t-value	p value
Intercept	-2.85689	0.19339	-14.773	<2e-16
Year	0.08666	0.09404	0.921	0.359
Random effect Grid = 0.7316				
Residual = 0.5563				

Lasionycteris noctivagans (Silver-haired Bat)				
	Estimate	SE	t-value	p value
Intercept	-2.9	0.14641	-20.255	<2e-16
Year	-0.1347	0.07032	-1.916	0.0582
Random effect Grid = 0.5636				
Residual = 0.4160				

Lasiurus cinereus (Hoary Bat)				
	Estimate	SE	t-value	p value
Intercept	-2.5565	0.1929	-13.255	<2e-16
Year	-0.1487	0.103	-1.443	0.152
Random effect Grid = 0.6112				
Residual = 0.6094				

Nycticeius humeralis (Evening Bat)				
	Estimate	SE	t-value	p value
Intercept	-2.4833	0.2108	-11.782	<2e-16
Year	-0.4549	0.1265	-3.596	0.000547
Random effect Grid = 0.3518				
Residual = 0.6694				

Table 3.2. Number of surveying years needed in Nebraska to obtain at least 80% power for 3 decline scenarios. Simulated data was generated for 9 groupings of years (4, 5, 6, 7, 8, 9, 10, 15, and 20) with imposed decline trends based on 3 scenarios for each species. Scenarios were an Amber decline (25% decline over 25 years), Red decline (50% decline over 25 years) and a Catastrophic decline (75% decline over 25 years). 1,000 simulations were created for each group of years with each decline scenario for each species and all species combined. The value below each scenario that is not in parentheses is the first of the nine groupings of years for that species where over 80% power was observed. The value below each scenario that is within parentheses is the actual power observed for the year listed above. Since year groupings past 10 skip 5 years at a time the actual year to reach the 80% threshold may be lower than what is reported below for the Amber decline scenario.

Species	**Amber** -1.144% per year	**Red** -2.735% per year	**Catastrophic** -5.394% per year
Big brown bat *Eptesicus fuscus*	15 (81%)	10 (81%)	7 (89%)
Eastern red bat *Lasiurus borealis*	15 (80%)	9 (89%)	6 (92%)
Silver-haired bat *Lasionycteris noctivagans*	15 (97%)	7 (82%)	5 (94%)
Hoary bat *Lasiurus cinereus*	20 (99%)	9 (83%)	6 (87%)
Evening bat *Nycticeius humeralis*	20 (88%)	15 (100%)	7 (89%)
All Species Combined	20 (92%)	10 (81%)	7 (89%)

Figure 3.1. Proportion of bat recordings by species across the entire state of Nebraska. Recordings that were unidentifiable, removed due to misclassification or from other species not included in this study have been removed. N. humeralis (evening bat) is only present in the Southeastern quarter of the state. All other species can be found throughout the entire state.

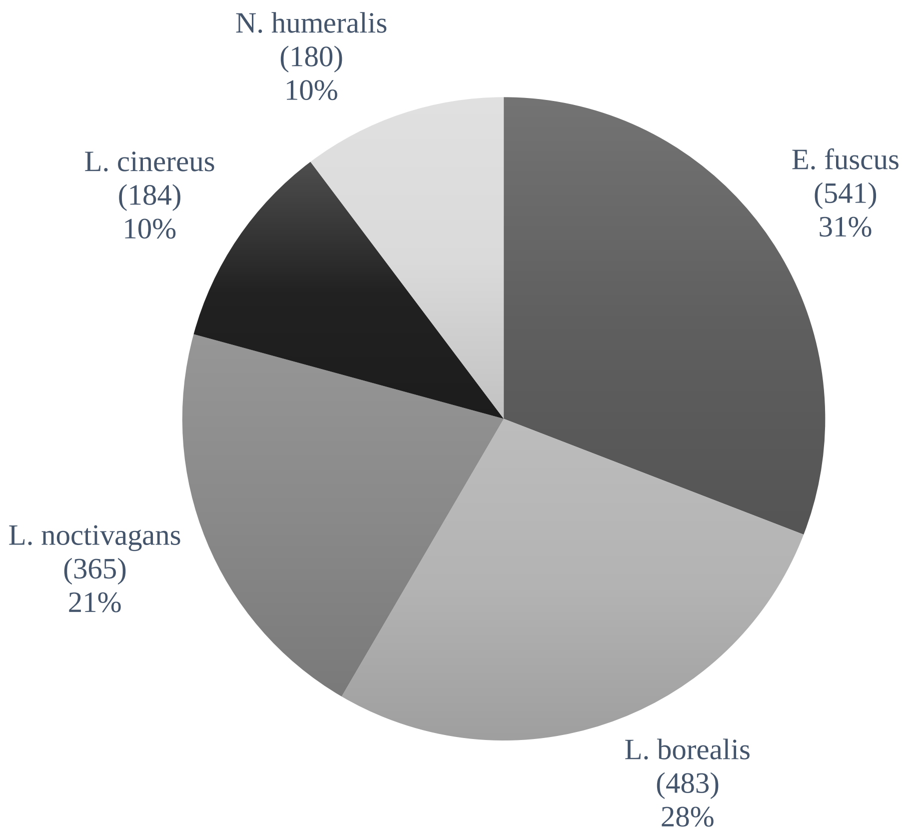

Figure 3.2. Activity levels of big brown bats, Eastern red bats, and silver-haired bats on transects throughout Nebraska. Shade represents the number of calls per hour of surveying time. Data collected on driving transects for NE NABat.

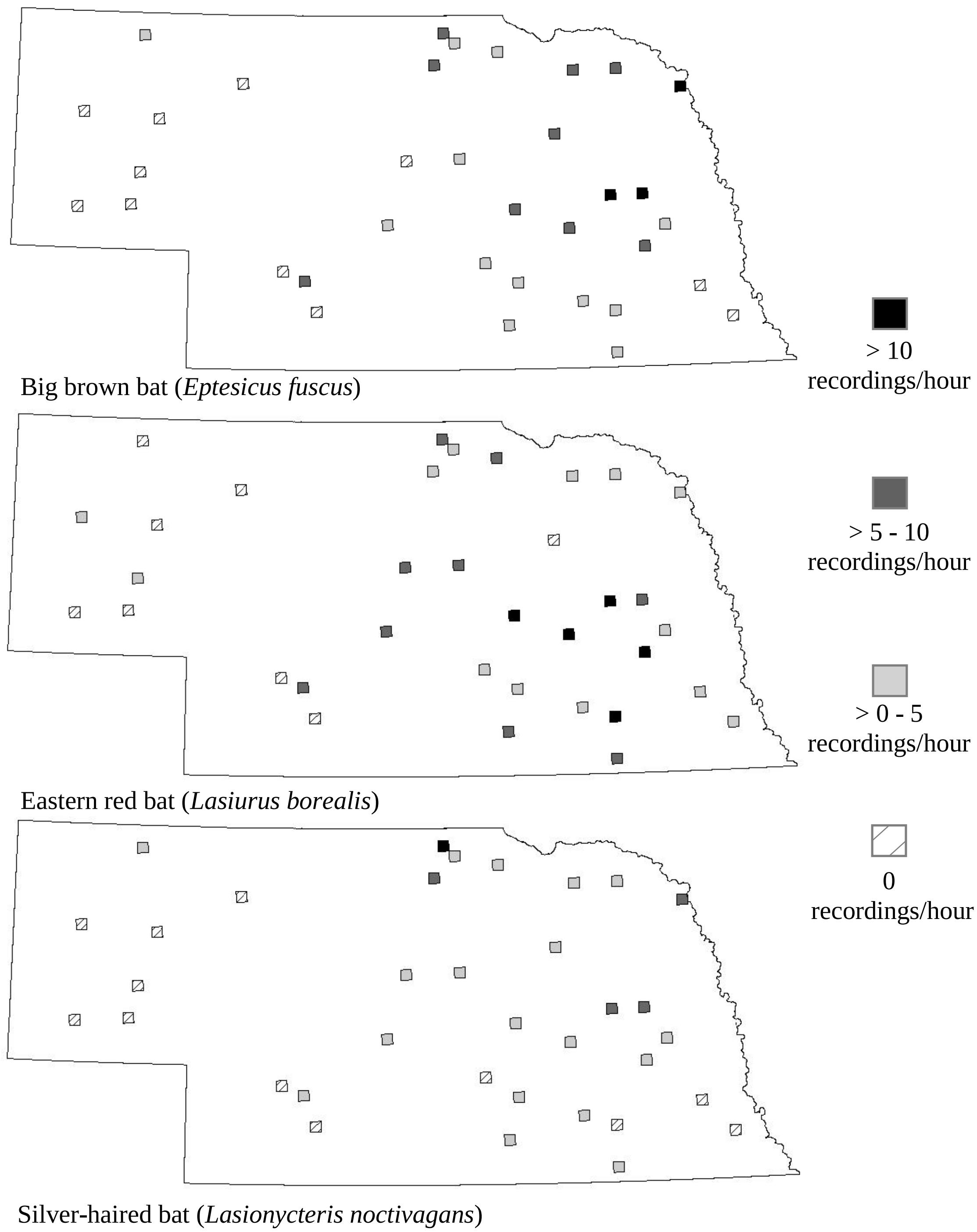

Figure 3.3 Activity levels of hoary bats, evening bats, and all species combined bats on transects throughout Nebraska. Shade represents the number of calls per hour of surveying time. Data collected on driving transects for NE NABat.

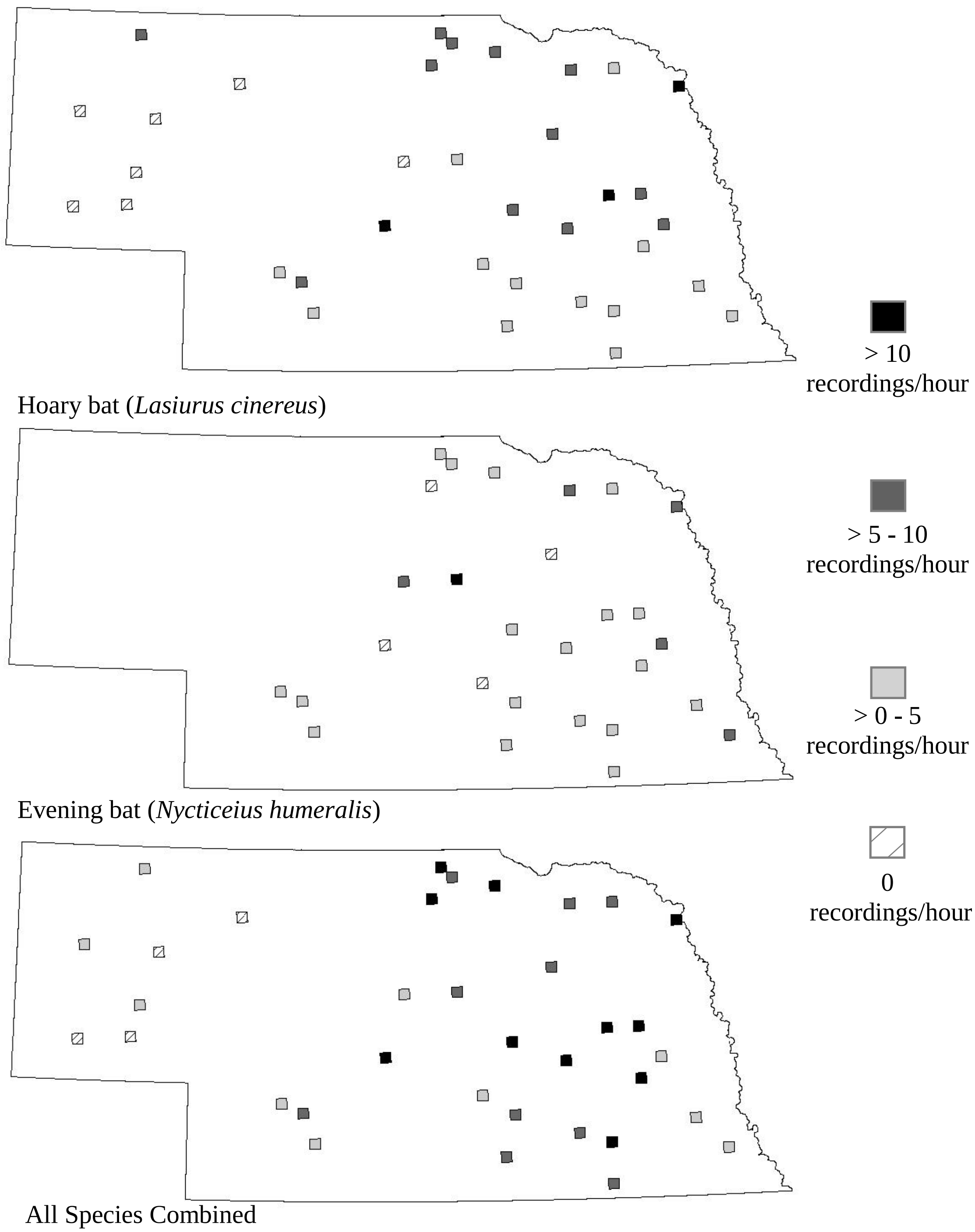

Figure 3.4. Power curves for each species and decline scenario showing how many years are required to reach 80% power. The grey horizontal line shows 80% power, dotted lines Amber decline, dot hash lines Red decline, and solid black line Catastrophic decline.