SINGLE-UNIT TURBINES AND BAT MORTALITY IN ARKANSAS

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ABSTRACT

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Wind power has become a substantial investment in the United States energy portfolio. It is approximated that by the year 2030, 30% of the world's energy will be produced by wind. An estimated 600,000 to 800,000 bats are killed in the United States every year by wind turbines. Using Anabat SD2, mist netting, fatalities searches, and two automatic-acoustic identifiers, I investigated six single-single unit turbines and their effects on bats in two ecoregions of Arkansas during the summers of 2012 and 2013. Netting effort totaled 30 nights with 94 bats captured during that time. I performed a combined 142 fatality searches resulting in finding 20 bat carcasses at one Delta turbine alone. A total of 17,017 hours of Anabat record time was logged. Bat Call Identification East read 159,788 files identifying 17,978 bat sequences to species level. Visual comparison to known-call libraries resulted in 90% efficacy for Bat Call Identification East (BCID). Echoclass read 157,788 files identifying 5,928 bat sequences to species level. Echoclass had a 74% efficacy from visual comparison. Suggestions for possible curtailment of fatalities due to wind turbines would be to conduct surveys before and after installment of turbine, site placement, and smaller rotor-swept areas.

ACKNOWLEDGEMENT/DEDICATION

First and foremost I have to thank my wife, Allison Jordan. You have been the rock that stood me up and kept me straight. You kept the goal in site, kept me focused, and gave me encouragement when things didn't seem like they were going to work. Next, I have to give love and thanks to my daughter Adyson. When your mother told me that she was pregnant with you I did not want to believe it. I truly wasn't ready for you, but you were on the way. Three days after you were born I had to leave for Iraq. The hardest goodbye I had to ever say, to that point. Even in the scariest times over there, the thought of you kept me focused on the mission at hand and getting back to you and your mother was my priority! Watching you grow up for eight months on a webcam from 5000 miles away was painful, but it got me through. Then I came home and you took to me like we had never been apart. The second happiest day of my life was that moment in Fort Knox, when for the very first time you reached for me and I knew, that you knew, I was your daddy. Right then I became aware that I had to become more. I had to step up my game to provide for you. I had to take this beautiful girl and show her that all things are possible. I had to show you that anyone can make a name for themselves. It is because of you that made me ready for this venture. Then we found out that your brother was coming. WOW, that was exciting! You weren't fully aware of who was coming, but you knew somebody special was in your mommy's tummy. You

talked about him like he was already there. Then, you had to leave us. That was the most difficult goodbye… How was I going to move on from being the center of one little girl's world to not having a little girl? That battle was one that I wasn't willing to fight. Baby girl, your little brother saved my life! I was ready to give up on everything. I couldn't have cared less about school after your accident, much less anything else. I had given up! Nathaniel James Jordan thank you for bringing me back to reality! You came along just at the perfect time. Your blue eyes looking at me in that hospital room gave me hope. Your little hand holding my finger was a great moral booster. I knew that I had to go from one step of my life into a whole other realm. I had to continue for you and your mother. You are everything to me, little man!

To my mother and father, thanks for the help I received throughout my life from you guys. Mom, how I wish you could be here as I receive my diploma. How I wish you could have been there for the many things that have happened and I wish you were here for the many things that are to come. You were a wonderful person and taught me how to love when loving someone was hard. Dad, thanks for showing me all that nature has to offer. All the hours spent on the river and out hunting with you really gave me the inspiration to become a wildlife biologist. You always taught me that if I cared for nature, nature would care for me.

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To my committee, thanks for all the hard work I have received from you! Dr. Virginie Rolland thanks for putting up with me when I got mad at the world. Again, I'm sorry for not coming and talking with you earlier. You're a really sweet person and I have a tremendous amount of respect for you. I have learned so much from you in the short time that we have known each other. Thank you! To the best violin playing professor I know, (Dr. Tanja McKay) thanks for helping on my committee. You became really busy soon after I asked you to be on my committee. Despite your other projects

you continued to take time with me and to help me complete this step in my life. The knowledge you have about insects is fascinating and thanks for sharing that. I'll have to go to Canada and see about those blackflies, all while singing the blackfly song in my head!

Elizabeth Rush and Heather DeMali, thanks for all the hard work you guys gave me while working as my technicians. I could have never done this project without you guys. I hope that your experience on this project was worth the time and I hope that I was able to help the both of you learn a little about bats.

To the scores of instructors and people whose path crossed mine over these years, thanks to every one of you! Each and every one of you have either taught me something new, reinforced something old, or have extended my knowledge on many subjects. Many of you have become my friends and will never be forgotten. If ever there is something I can do for anyone of you guys I will do whatever it takes. That's the love that I felt during my time at Arkansas State University!

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CHAPTER I
INTRODUCTION

Wind Energy

In response to climate change, many alternatives to carbon-based energy have been considered and developed for a cleaner and environmentally friendlier energy source; wind power, biofuels, and solar collection are solutions for removing carbon-based energy from the U.S. energy portfolio. Many have sought a cleaner solution in wind energy and have turned to wind turbines, structures that harness the power of wind to produce energy.

Single-unit turbines or small-wind turbines typically have under 50-kW capacity and can harness 50 kW of power under optimal wind conditions. The turbine, in return, converts that power into energy that is then used by consumers. Energy is measured in kilowatt hours, in theory, a 50-kW wind turbine (under prime conditions) can produce 50 kW of power for 24 hours a day for 365 days a year. The wind-turbine industry states that turbines are approximately 30-40 % efficient (Endurance Wind Energy 2013). Thus, a 50-kW turbine with an efficiency of 40 % is 50 kW*24hrs*365days*40% or 175,200 kW hours in one year. This would be enough energy to power a large farm, a hospital, or several homes. In the last 12 years, the capacity of energy produced by wind power has risen from 2.5 Gigawatts in 2000 to 6.0 Gigawatts in 2012 (Global Wind Energy Council

2013), the equivalent of 210 terawatts ($2.1x10^{14}$ watts) hours of energy. The Global Wind Energy Council estimates 20% of all energy produced in the U.S. will be wind energy by 2030, ten times the current wind production in the U.S.

Large wind farms are placed in areas where the wind is the strongest and consistent. These areas are classified into wind-power densities ranging from class 1 (weakest wind) to class 7 (strongest and consistent winds). According to the U. S. Department of Energy, class 4-7 wind regions (>7m/s) are suitable for large-scale wind farms (NREL 2010). Single-unit turbines can be placed in class 3 or lower wind speed category. Currently, regions throughout the United States with the best wind potential are from Montana south to Texas (Great Plains) and in the coastal waters of the Pacific and Atlantic Oceans (Fig. I.1). Northwest Arkansas is rated as a class 3 wind producer with annual speeds of 6.4-7.0 m/s, indicating that this area is suitable for single-unit turbines (Fig. I.2). The Arkansas Delta is rated by the Department of Energy, in having low wind speeds, a class 1 wind producer (Fig. I.2).

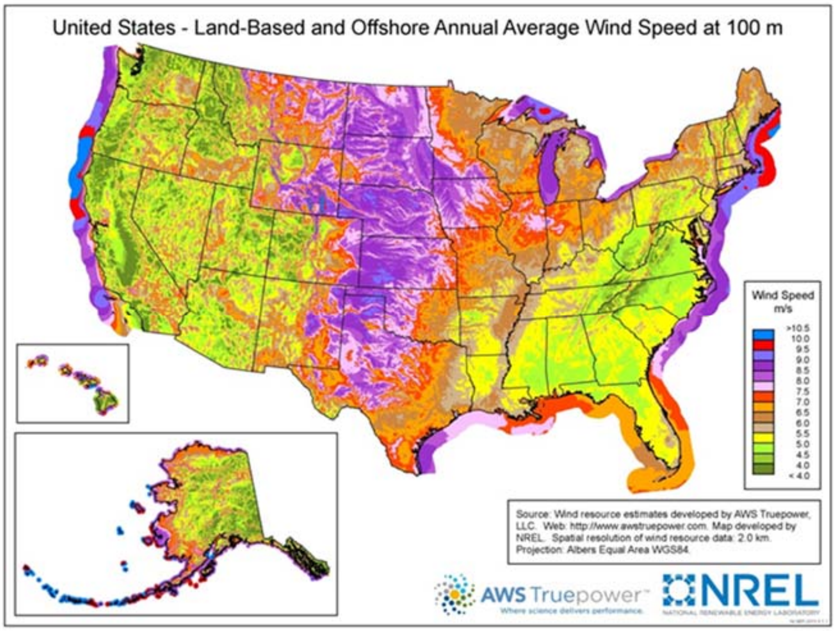

Figure I.1: Coastal and mainland United States wind speed density at a height of 100 m. The greatest winds are in the Central Plains and along the coast. Wind resource map developed by NREL with data from AWS TruePower 2010.

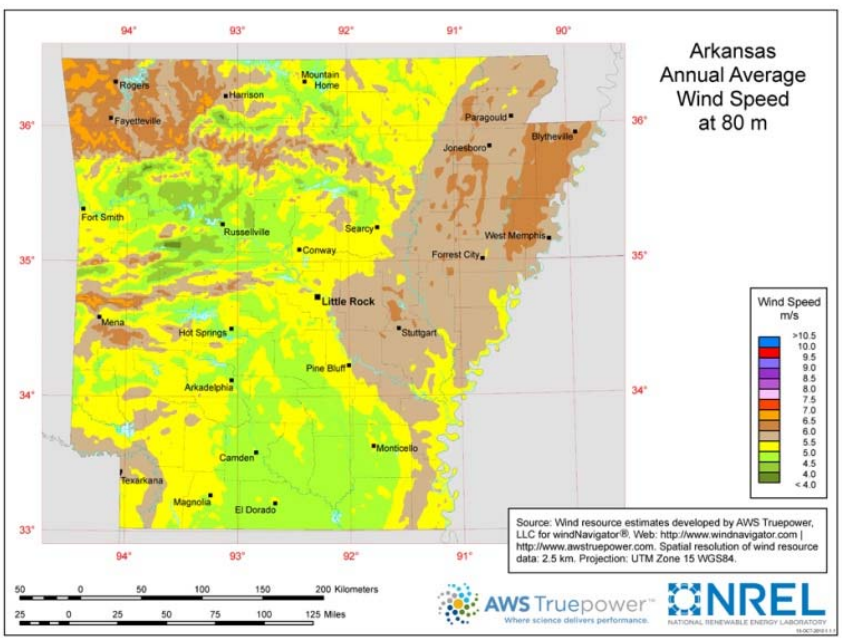

Figure I.2: Wind speed densities in Arkansas at 80 m (NREL 2010). Lighter shades of yellow (NW Arkansas) indicate Class 3 wind density, with light brown and tan in NE Arkansas indicate Class 1 and 2 wind density. Wind resource map developed by NREL with data from AWS TruePower 2010.

Wind Turbine and Wildlife Fatalities

Initially, birds received a majority of the attention from turbine-related fatalities (Leddy et al. 1999, Osborn et al. 2000, Smallwood and Thelander 2007). However, when on a routine bird search at the Buffalo Ridge Wind Facility, in Minnesota, many dead bats were found mortality wounded (Arnett et al. 2008). The first reported fatalities of bats from wind facilities were in 1972 when over a four-year period, 22 white-striped mastiff bats (*Tardarida australis*) were found under or near a turbine site in Australia (Hall and Richards 1972). Fatalities have been repeated worldwide in countries such as Spain (Camina 2012), Germany (Brinkmann and Bontadina 2006), and in the U.S. (Johnson et al. 2003). Hayes (2013) states approximately 600,000 bats are mortally wounded at turbine facilities in the U.S., while Smallwood (2013) estimates 888,000 bats are killed each year due to large-wind facilities in the United States.

Foraging height of many bats in the Southeastern U.S. is 2-30 m (Menzel et al. 2005) making them at risk in colliding with the blades of turbines. The blades of single-unit turbines are typically 21 m or smaller in length placed at the top of a 42.7-m or smaller towers (Endurance Wind Energy, Surrey, Canada). The height of the tower and length of the blades places the rotor-swept area (area covered by the moving blades) in the foraging zone of many bats.

Bats that are being affected by large-scale wind farms are migratory tree-roosting species (Arnett et al. 2008). The migration of these animals and the timing of their deaths at many wind facilities in the northeastern U.S. have been strongly correlated, with more deaths being reported during autumn migration (Johnson et al.

2003, Reynolds 2006, Cryan and Veilleux 2007, Arnett et al. 2008, Cohn 2008). Migration behavior, much like birds, consists of temperate forest bats moving from northern summer roosting locations to southern winter roosting locations for warmer temperatures (Cryan and Veilleux 2007). A possible reason for more reported deaths in autumn, as explained by Cryan and Veilleux (2007), is that these bats might fly at lower altitudes during spring than during autumn migration. The hoary bat (*Lasiurus cenarius*), eastern red bat (*L. borealis*), and the silver-haired bat (*Lasionyteris noctivagans*) are the species being regularly impacted by large-scale facilities (Johnson et al. 2003, Reynolds 2006, Arnett et al. 2008, Cohn 2008). The rate at which the tree-roosting species are being impacted is high in many places. For example at Buffalo Ridge, Minnesota, rates were consistent among all of the 354 turbines on the studied farm, killing an average of 2.0 bats per turbine per year (Johnson et al. 2003). Also, in Mountaineer, West Virginia, 2092 bats died during a 68-day survey conducted at 44 turbines, resulting in a rate of fatalities of 47.5 bats per turbine (Kerns and Kerlinger 2004). At Buffalo Mountain, Tennessee, 21 turbines killed an estimated 3.0 bats per turbine per year. Fiedler et al. (2007) indicated that 91% of those bats killed in the above examples were eastern red bats. The migrating species found at large-scale wind facilities rarely included endangered species with only four Indiana myotis (*Myotis sodalis*) bats being reported during the years of 2009-2012 (Lovering 2011, Good et al. 2012, Pruitt and Okajima 2013).

Arkansas Bats

These wind-turbine impacts, especially, on forest-roosting species and the possibility of White Nose Syndrome impacting Arkansas' endangered cave species makes the construction of wind turbines in the Ozark Plateau of Arkansas a conservation concern.

The Ozark Plateau in central and northwest Arkansas is comprised of > 70% karst limestone (Arkansas Geological Survey 2012). This area provides a suitable habitat for populations of federally-protected cave-dwelling bats, including the gray myotis (*Myotis grisescens*) and the Ozark big-eared bat (*Corynorhinus townsenii igens*). The Indiana myotis, also federally protected, roosts in Arkansas' forests during the summer and 11 counties in the Ozark Plateau have known hibernacula (Gardner and Cook 2002). Also, the U. S. Fish and Wildlife Service has proposed the listing of the northern long-eared bat (*M*. *septrionalis*) (Parham 2014), a species found in Arkansas, with similar hibernating and roosting ecology as the Indiana bat (Barclay and Kurta 2007). The gray myotis, Indiana myotis, and the northern long-eared bat have all had significant mortality events from White-Nose Syndrome since 2006 with an estimated total mortality of 5.5 million bats in the U.S. (National Wildlife Health Center 2014). Wind turbines could cause these species to become more imperiled. The Endangered Species Act (ESA) of 1973 disallows for the illegal take or killing of endangered species, even if that take is unintentional due to equipment installed on the owner's land or project site.

If an animal is discovered dead on the property, the landowner could be reprimanded or fined (ESA: Section 9 (a) USFWS 1973).

Bat Acoustics and Species Identification

Echolocation or echo-imaging orientates a bat by using sounds emitted from their mouth to gather information about their environment despite light conditions (Griffin 1958, Fenton 1984). The production of echolocation pulses are provided through the contraction of the abdominal muscles from the downward stroke of the wings. The contraction of the muscles forces air through a small opening in the larynx (Neuweiler 2000). All of the southeastern United States bats use ultrasonic [> 20 kilohertz (kHz)] echolocation pulses to communicate with their environment and to find prey. If the bats are in clutter (i.e. thick forest conditions) or actively chasing a prey item, they will increase their echolocation pulses (Chris Corben, Titley Electronics, pers. comm. 2012). There are three different types of pulses identified in bat acoustics: downward frequency modulation (starts at high frequency ends at lower frequency), constant frequency (frequency stays the same or slightly modulated from the inception to ending of the pulse), and upward frequency modulation (pulse begins at a lower frequency and ends at a much higher frequency) (Neuweiler 2000). Bats in Arkansas have pulses ranging from 12-105 kHz with downward frequency modulation. The exception is the Rafinesque's big-eared bat (*Corynorhinus rafinesquii*), which has elements of constant frequency within a search call (Fig. I.3). The migrating-forest bats that fly at higher altitudes use lower frequency to reduce attenuation from air (Neuweiler 2000), which puts them at greater risk of colliding with turbine blades.

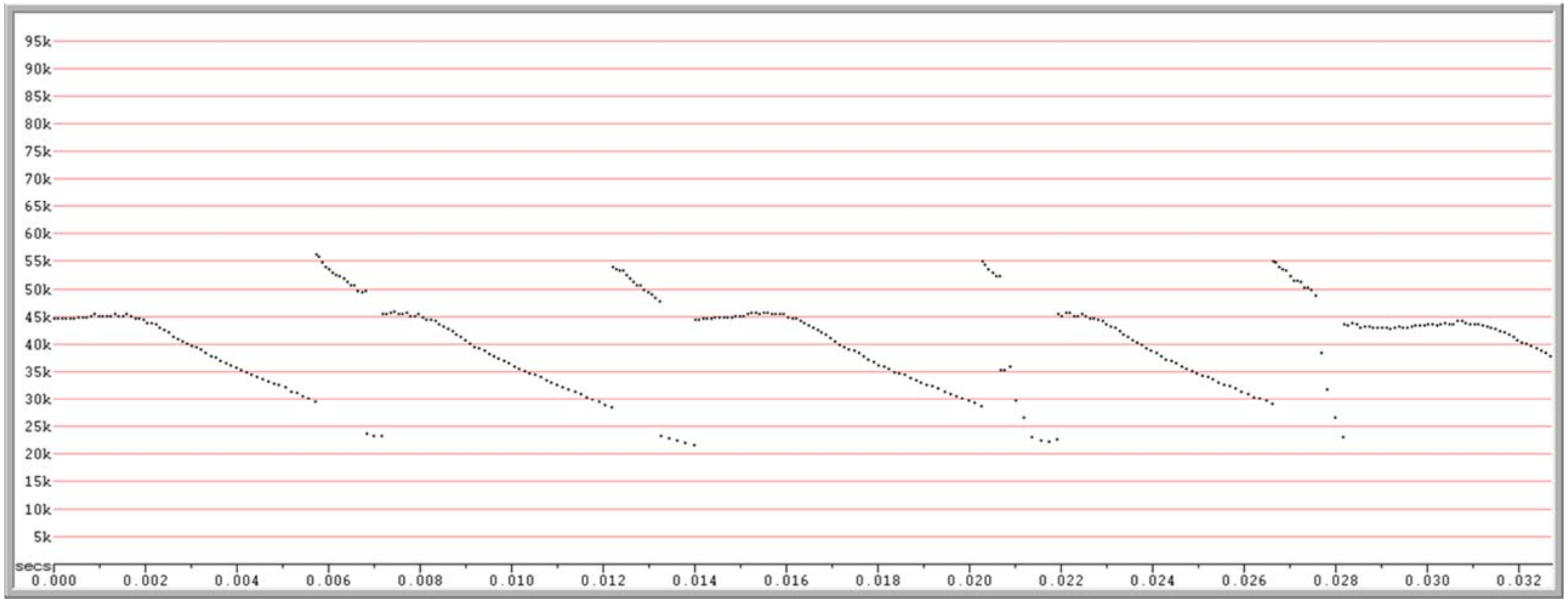

Figure I.3: Rafinesque's big-eared bat (*Corynorhinus rafinesquii*) echolocation pulses. The pulse stays constant at 45 kHz for 0.002 seconds, illustrating constant frequency before beginning a downward frequency modulation (Analook, Titley Scientific 2012).

During the late 1980s and early 1990s, bat detection devices, Anabat (Titley Electronics, Ballina, NSW, Australia) or SM2BAT (Wildlife Acoustics, Concord, MA) became readily available to researchers (Gannon et al. 2003). Recently, this technology became more useful in the field, but debate has continued about the reliability of these systems to accurately identify bats at the species level (Barclay 1999, O'Farrell et al. 1999, O'Farrell and Gannon 1999, O'Farrell and Miller 1999, Britzke et al. 2011). Bats, much like birds, can be identified to species using qualitative observation of the call structures in programs like Analook (Titley Electronics) or Sonobat (Wildlife Acoustics), (O'Farrell and Gannon 1999). However, species echolocation pulses are highly variable and many species simply cannot be identified reliably by their pulses using these systems (Barclay 1999).

In studying the efficacy of bat detection devices, nearly three times as many bats were detected using the Anabat 2 system (Titley Electronics, Ballina, New South Wales, Austrailia) as with mist-nets only (O'Farrell and Gannon 1999). Two written tests were created to determine the accuracy of qualitative methods and experience employed to identify bat species in the above mentioned programs (O'Farrell et al. 1999). These written tests consisted of several known echolocation pulses taken from free-flying bats. The authors took the test with results for Gannon being 62.5% of 48 known pulses from 18 different species and 90.8% of 65 known pulses from 13 different species answered correctly on the second test. O'Farrell successfully identified 89.6% and 96.9% using two different tests, providing evidence that with experience, many people can identify species' pulse structures with this technology.

Using quantitative data described below and program R (R Core Team 2013) Britzke et al. (2011), performed discriminate function analysis (DFA), for the validation of these systems with a success rate of 0.94. O'Farrell and Gannon (1999) argued that because of limitations of bat detectors, clear definitions are needed and several parameters being species-specific must be considered together for a more reliable identification. These parameters (defined as features on a sonogram) are minimum frequency of a pulse (Fmin), maximum frequency of a pulse (Fmax), slope change frequency (F, where the slope of a pulse sequence moves from the flattest point to the start of the slope), and the frequency at which begins the slope change (Fc). Britzke et al. (2011) classified a pulse as one emission of sound and a pulse sequence as several pulses emitted by an individual bat with < 1-s pause between pulses. Additionally, accuracy can be increased if S_I (Initial slope), S_c (flattest section of pulse), F_k (where slope changes from S_I to S_c), F_{mean} (mean frequency of pulses), and Dur (duration of pulse sequence) are also included in analysis. Using these characteristics, > 90% accuracy was found in identifying two of the three endangered bat species of Arkansas using DFA (Britzke et al. 2011). After numerous rounds of testing, a program named Echoclass was developed in order to automatically identify bat calls using the above statistical analysis (Britzke 2013).

Bat Call Identification (BCID East, Ryan Allen 2010) uses the same parameters, but analysis is performed using classification tree analysis. This analysis was developed in order to determine which predictors (parameters) are most important in classifying a particular data set (Morgan 2014). The predictors are given a weight per parameter tested and a final discriminate probability is given.

Eleven assumptions need to be checked when determining the usage of acoustic devices (Sherwin et al. 2000). These assumptions are as follows: 1) Correlation of call structure in a particular habitat; 2) All calls are independent events; 3) What defines a call capture (number of pulses recorded)? 4) Will a call be defined as a feeding call or a search call? 5) Species identification or grouped into guilds? 6) Random distribution of bats through vertical space. 7) Categorical assignment of guilds in a particular habitat? 8) Replication of multiple systems along several habitats through differing years? 9) All guilds had the same detection probably? 10) Time and space of calls are corrected through multiple sampling. 11) All results are on a local level. Furthermore, Gannon et al. (2003) researched 50 papers detailing acoustic surveying and identified violations of these assumptions. Out of the 50 studies, only 12 clearly defined and corrected the above stated assumptions (Gannon et al. 2003). They then tested these assumptions using their own field study and found that a correction of these assumptions should be identified before the onset of an acoustic study.

Objectives

The goal of this study was to identify whether single-unit turbines are harming federally-protected bats in the state of Arkansas. My specific objectives were to (1) set a base-line for projects including single-unit turbines and bat mortality; (2) describe what land characteristics are conducive to bat mortality; (3) determine if rotor-swept area is correlated with bat mortality; and (4) describe bat activity around turbines. If these objectives are achieved, recommendations can be made to the USFWS about problematic placement or possible curtailment of bat fatalities.

During this study, single-unit turbines and bat mortality were investigated with importance placed on federally-protected species of bats. The proposed questions that were addressed:

1. What species are impacted by single-unit turbine systems?
2. Does a larger rotor-sweep area result in more fatalities than smaller sweep areas?
3. Are there more bat fatalities during migration?
4. What land-use characteristics are related to higher numbers of bat collisions with turbine units?
5. When are bats most active?

Based on literature, the following predictions were made:

1. Previous studies reported that bat fatalities were greater in forest bats (Reynolds 2006, Kunz et al. 2007, Arnett et al. 2008, Cohn 2008, Horn et al. 2008). I predicted most fatalities will be that of forest roosting species including Eastern-red bat, hoary bat, and silver-haired bat.
2. I predicted a larger diameter rotor-swept area to have a greater number of fatalities than smaller diameter rotor sweep. Greater numbers of bat fatalities were reported at Alberta (Canada), Buffalo Mountain (Tennessee), and Buffalo

Ridge (Minnesota) wind farms after the installation of turbines that have a greater rotor-swept area (Arnett et al. 2008).

3. Bats aggregate in large numbers and migrate during time periods of mid to late fall and early spring. Many fatalities were observed after large migrations (Reynolds 2006, Kunz et al. 2007, Arnett et al. 2008, Cohn 2008, and Horn et al. 2008). I predicted that fatalities would be evenly spread throughout the time period surveyed.
4. Wind-turbine projects create a substantial amount of open space in forested areas. Bats are known to use these areas in forested landscapes as a foraging location (Loeb and O'Keefe 2009). Thus, I predicted forested areas to incur more fatalities than that of urban landscapes (Arnett et al. 2008).
5. Emergences of smaller bats that prey on insects that peak during times of lower light emerge at sunset (Rydell et al. 1996). Larger bats that seek larger insects emerge approximately one hour after sunset, because larger night-time insects do not emerge later in the evening (Lacki et al. 2007). I predict that the greatest time of activity will be approximately one hour after sunset.

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CHAPTER II
MATERIALS AND METHODS

Study Sites

Bat surveys were conducted during summers 2012 and 2013 on six single-unit wind turbines throughout the northern region of Arkansas: three sites in the non-karst region (Mississippi Alluvial Plain) of the state and three sites in the karst region (Ozark Mountain) of the state (Fig. II.1).

Figure II.1: Ecoregions of Arkansas. The Karst region located in the Ozark Mountains (West Arkansas) and the Delta region located in the Mississippi Alluvial Plains (East Arkansas)(National Park Service 2014).

The karst region is of particular importance because the region is necessary for the hibernation of Arkansas' endangered bats. The three western sites (Fig. II.2) were near the cities of Prairie Grove (Urban), Springdale (Urban), and Ponca (Forested). The Prairie Grove turbine is a large non-operational 100-kW maximum capacity turbine situated on a monopole tower. The turbine rotor-sweep area is 293 m^2. The turbine is ~ 0.29 km from Muddy Fork Creek which could support bat travel and foraging. The turbine is located on property that has industrial businesses on all sides. The study site in Springdale is located < 0.10 km from Hwy 71B and is behind a large church. There are three 2.4-kW turbines each on a monopole tower. Two of the turbines are 13 m tall and the other is 18 m tall. Each turbine has a rotor-sweep area of 10.8 m^2. This area is heavily urbanized with a sparsely wooded park < 0.5 km east of the study site. The turbine in Ponca is 10-kW maximum capacity with a rotor-sweep area of 38.5 m^2. The turbine is on a three-legged lattice tower structure. This turbine is at an elevation of 194 m with a highly forested landscape surrounding the area. This turbine has a pond < 0.10 km away which could provide bats with foraging and watering opportunities. The owner of the property has a home approximately 0.15 km away from the turbine location.

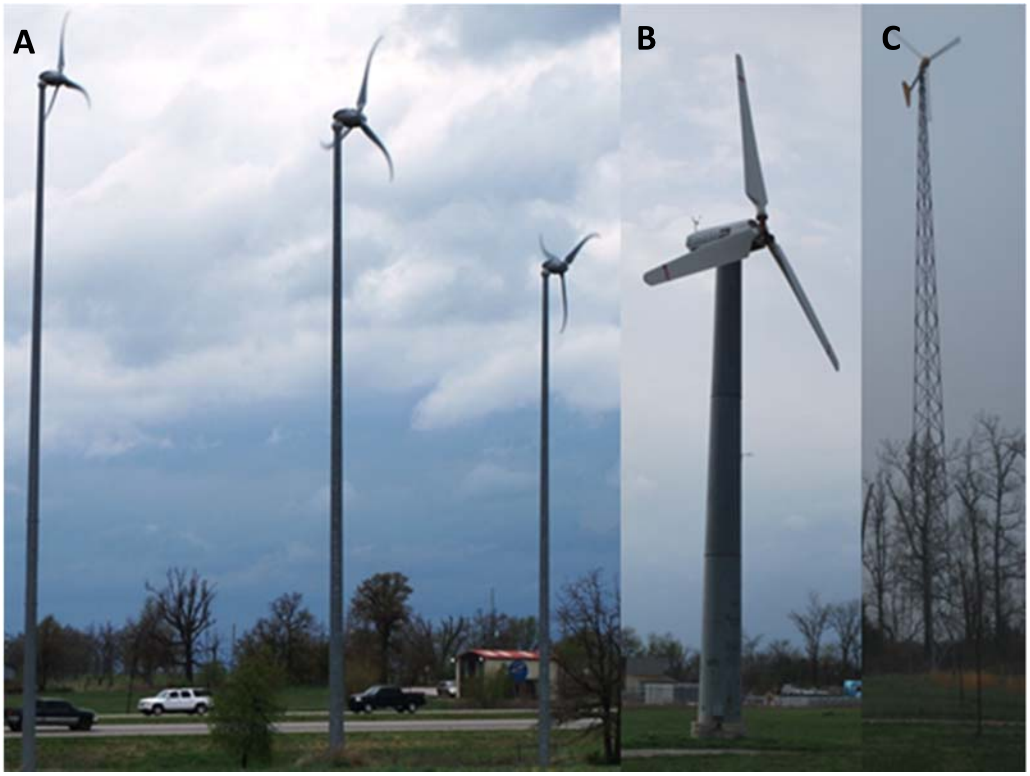

Figure II.2: Turbines in the karst region of Western Arkansas. A) Springdale, B) Prairie Grove, and C) Ponca. The turbine at Prairie Grove was not operational during this study.

The three survey areas on the eastern side of the state (Fig. II.3) were in the cities of Burdette (Agriculture), Fair Oaks (Agriculture), and Diaz (Agriculture). The turbine in Burdette is a 50-kW maximum capacity turbine on a monopole tower structure. The area around this study site is mainly represented by agricultural crop and cattle land. The rotor-sweep area is 290 m^2. This turbine was erected in the spring of 2011 and was non-operational throughout the study period. There is a city fishing pond located ~ 0.5 km from the study site. The study site in Diaz has a 50-kW maximum capacity turbine placed on a lattice tower. Village Creek, a major forested waterway in the area, is < 0.75 km west of the Diaz site and a large water-retention pond is located ~ 1 km east of the study-site location. Also, the study site is located ~ 11 km east of the White River and ~ 15 km from the Cache River, both could be used as travel corridors (Hein et al. 2008). The waterways near Diaz and Prairie Grove are conducive for bat foraging and travel (Adam et al. 1994). The Fair Oaks study site was surrounded by agriculture cropland. The vegetation was minimal and corridors were lacking. A large retention pond near the site gives bats a watering source. There are highly-traveled roads on the north and west of the turbine location.

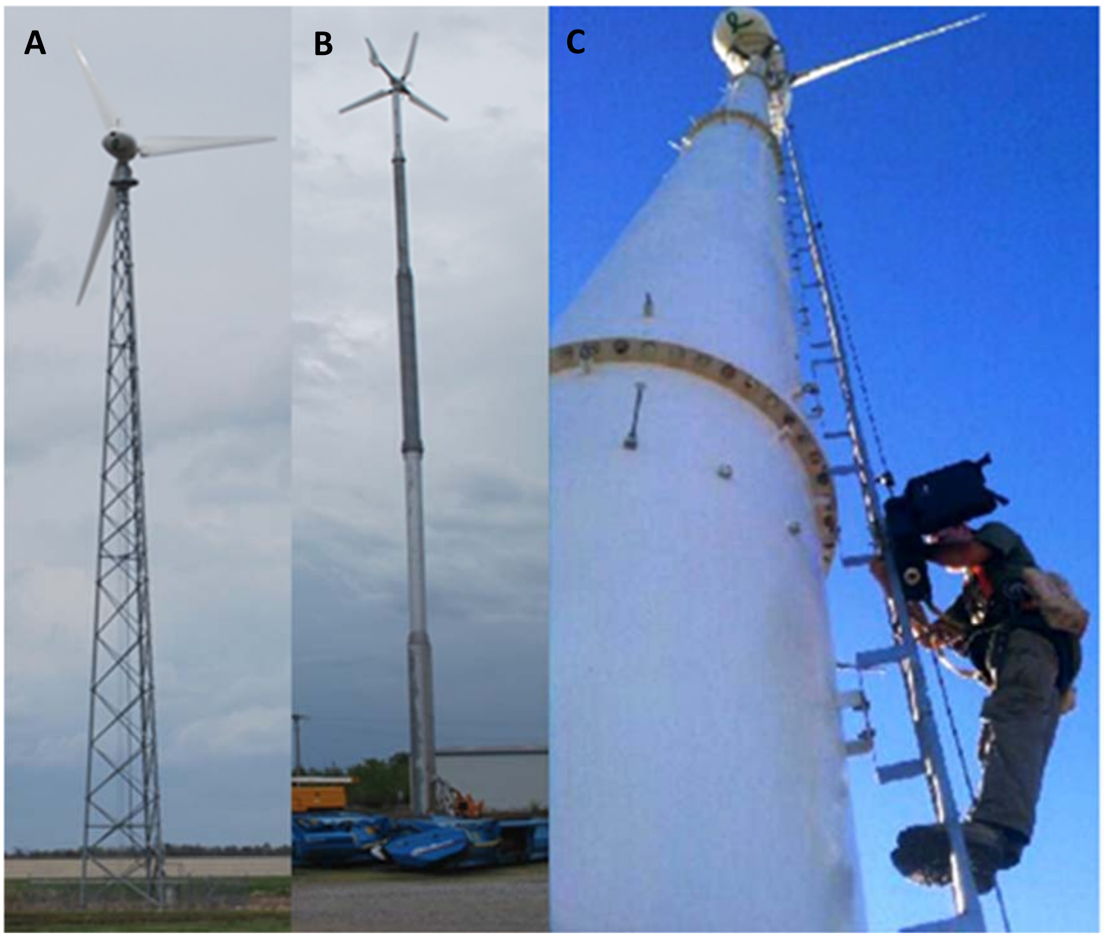

Figure II.3: Turbine sites in the Delta Region of Eastern Arkansas. A) Diaz, B) Fair Oaks, and C) Burdette. The turbine in Fair Oaks was operational for two months during 2012. The turbine in Burdette was never operational during the time surveyed.

Each site was surveyed with bat detectors and mist-nets. Bat mortality was surveyed around the turbine as well. This provided information about species composition, species impacted, and times at night when activity level was greatest.

Landscapes

Bat habitat requirements are roosts, proximity to water, and foraging locations are resources that may be limited in certain areas (Ball 2002, Loeb and O'Keefe 2009). Landscapes for each particular study site were classified into three categories: urban, forested, and agriculture. Urban landscapes are comprised of high anthropogenic influences (i.e., street lights, trash bins, and other insect attractants), which bats find attractive (Mager and Nelson 2001). Forested landscapes have high density of timber. Forest-roosting bats typically find refuge in many types of trees throughout this landscape. Hollow trees, snags, and trees with high amounts of peeling bark are where a majority of forest bats roost during summer months (Callahan et al. 1997, Kalcounis-Ruppell et al. 2005). An agricultural landscape attracts insects and is of importance to bats as well (Cleveland et al. 2006). Bats are a major predator to agriculture pest (Boyles et al. 2011). Although each of these areas have a mixture of all attributes noted above, the designation for each area was given based on the dominant (> 75%) landscape around the turbine.

To determine what landscape type is surrounding a particular turbine site, ArcMap 10.2 (ESRI 2014) was used. A two-kilometer buffer was established around the turbine site in order to ascertain landscape characteristics (Fig. II.4).

Figure II.4: Two-kilometer buffer around each turbine location (black asterisk). Upper left to lower right: A) Ponca, B) Springdale, and C) Prairie Grove are all located in the karst region of Arkansas. D) Fair Oaks, E) Burdette, and F) Diaz are located in the Delta Region of Arkansas (scale = 1:25,000) (ArcMap™ 10.1 ESRI 2012).

Mist-netting

Although the use of acoustic detectors is valuable, many automated-acoustic-identifications are considered false positives (Clement et al. 2014). Therefore, mist netting was an essential part to determine which species frequented the turbines. I used mist-net data to determine the local composition of bat species using the area of the wind turbine to be sampled on a given night. Net lengths and heights depended on conditions at each location. Typical nets used for bat surveys are Avinet (Dryden, NY) 75/2, 38-mm mesh, 2.6 m high, and from 4 to 18 m long. Height of canopy at the location determined the mist-net height (2.6 m-7.8 m) to be used. After setting the mist-nets (before 19:00), they were opened 15 min prior to sunset and left opened for five hours. Also, depending on the landscape of the study areas, the number of mist-nets varied. When many sites were available within the area, two sites were chosen and nets were set according to the dimensions of the restricted flyway. Many net sizes were used. Nets with the dimensions of 7.8 m x 12.0 m nets were most common, although many varying sizes were used depending on availability of habitat. A net with the dimensions of 7.8 m x 12.0 m equals a total of 93.6 m^2 (1008.6 ft^2) area. The set up mentioned above, was used to funnel and restrict riparian corridors often used by bats for travel and foraging (Rogers et al. 2006). Each site was mist-netted one or two times every three weeks (Fig.II.5), with the exception of Fair Oaks and Springdale in which no netting was conducted. Locations were never netted on back-to-back nights to reduce learned response, where bats could become aware of the nets and avoid capture (Winhold and Kurta 2008).

Figure II.5: A 7.8 x 4 m standard triple-high mist net in a creek west of the Prairie Grove turbine. An area that is narrow with dense vegetation on each side and low tree canopy funnel bats towards the nets.

For each captured bat, I recorded species, measured forearm length and mass, assessed reproductive condition (i.e., estrus, lactating, or non-reproductive), and determined sex by visually inspecting the genital region of the animal (Racey 2009), age (juvenile vs. adult) based on ossification of the cartilage in the fourth digit between the metacarpal and phalangeal joint (Brunet-Rossinni and Wilkinson 2009) (Appendix 2).

Acoustic Surveying

Acoustic passive monitoring was conducted nightly over the period of May-October of 2012 and 2013 using an Anabat SD2 (Titley Electronics, Ballina, NSW, Australia). The Anabat was programmed to begin recording at 19:00 every night and end recording at 06:30 the next morning. Numerous studies have used passive monitoring to provide secondary surveys along with mist-net surveys (Johnson et al. 2002, Gannon et al. 2003, Preatoni et al. 2005, Reynolds 2006, Arnett et al. 2008, Gorresen et al. 2008, Britzke et al. 2011). Passive monitoring was conducted by leaving one Anabat SD2 placed in a Pelican™ Storm Case™ IM220 (Pelican Cases, Tempe, AZ) at each study site placed on the southwest side of the tower supporting the turbine (Fig.II.6). A five-inch square plexiglass bounce plate was attached to the box with a 5-cm flat bar bent up at a 45˚ angle. This set up allowed for calls to be reflected off the plate and into the microphone. If the tower could not have the box placed on it, the next tallest structure was used, which only happened with the Prairie Grove turbine, where the box was placed at 4 m on the industrial building 10 m from the actual turbine.

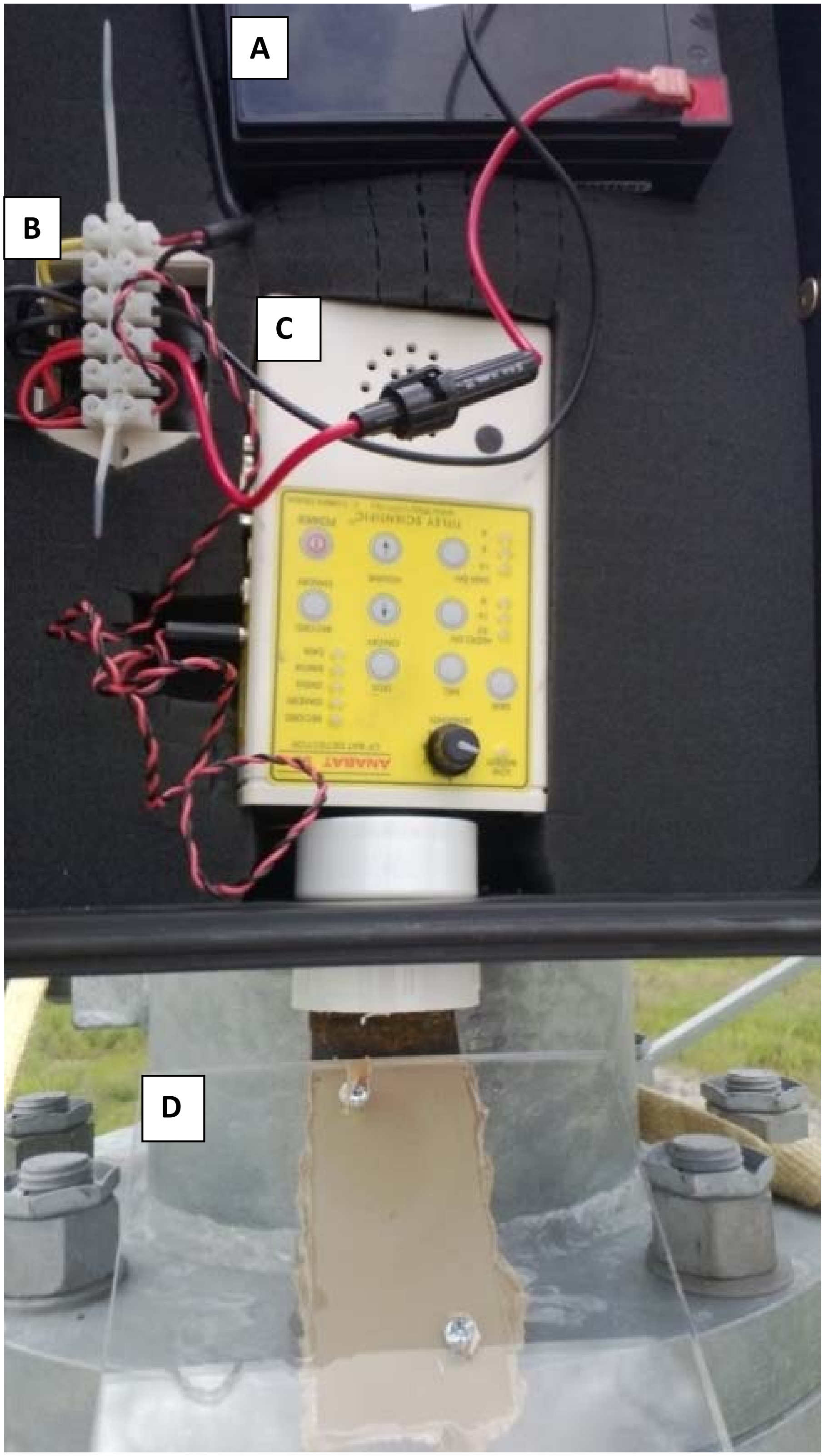

Figure II.6: Anabat SD2 (Titley Electronics) passive-acoustic setup placed six meters high on a tower leg. A) 12-V battery B) Solar Controller C) Anabat SD2, and D) Bounce plate. The bounce plate allows for reflection of calls into the microphone of the detector.

There was a Sunwize 3.5-Watt solar panel (San Jose, CA) connected to a Sunforce (Montreal, Canada) 7-Amp charge controller. The charge controller prevented overcharging of the Power Sonic 12-V battery that was charged by the solar panel. During days of minimal sunlight, the battery kept enough charge to provide power to the Anabat. Each pass of a bat was recorded and stored on a 2-GB compact flash card stored in the detector. Every two weeks the compact flash card was retrieved and replaced with a new card. Each call recorded was given a timestamp by the detector in the format of mmddtttt (month, day, time), meaning if a call was recorded at 2304 July 2, the timestamp was 07022304. This was used to know what time bats were active. Information from the card was accessed by CFCread (Titley Scientific, Columbia, MO). The data retrieved from the two-week collection time were stored on an external hard drive and a laptop computer.

Sensitivity of the Anabat SD2 was tested using Dog Whistle 7 (Bee Sprout, Kissimmee, FL) set at a frequency of 30 kHz, one meter from the bounce plate. When the Anabat picked up the frequency, the sensitivity was then set. All Anabats registered 30 kHz at one meter with a sensitivity setting of four. After initial setting of sensitivity, a two-week trial period was instated with the Anabat sensitivity set on four. This setting worked for five of the six study sites. During 2012 Prairie Grove had an abundance of tall vegetation close to the Anabat, which caused the Anabat to register two weeks of insect noise. Thus the sensitivity was turned down to two for another two weeks. Again the Anabat registered insect noise. Finally, the sensitivity was turned down to one and insect noise was not as high, but acoustic detection of bats suffered.

Acoustic Analysis

Bat Call Identification East version 2.6a (BCID 2013, Ryan Allen, Kansas City, MO) and Echoclass 2.0 (Britzke 2012) were used to determine the species composition of surveyed areas. These programs automatically identify a call using statistical analysis on the parameters (Chapter 1) to identify recorded species-level calls. The program allows for choosing specific species that are related to a certain region. In BCID I chose all species that are relevant to north Arkansas. While using Echoclass I chose set 1, which includes all Arkansas bats with the exception of the Brazilian free-tailed bat (*Tadarida brasiliensis*), Ozark big-eared bat (*Corynorhinus townsendii ingens*), Rafinesque' s big-eared bat (*Corynorhinus rafinesquii*), and the Seminole bat (*Lasiurus seminolus*). There were no other filters or limitations placed on the programs. The program automatically produces a spreadsheet with species identification and gives a probability value allowing the user to determine if the program is accurate in its analysis. I only retained the calls with the highest identification confidence by applying a filter that extracted calls with 10 or more pulses and a probability of 0.85 or higher. To test the efficiency of BCID and Echoclass, Program R (R Core Team 2014) was used to randomly select 100 calls for a visual comparison. Murray et al. (2001) collected pulse sequences on known bat species throughout the Midwest. They compiled these pulse sequences into the Midwest Call Library. Titley Scientific (2012) also created a call library in a similar manner as Murray et al. (2001). Program AnalookW v 4.1 (Titley Electronics, Columbia, MO) allows for visual comparison of the call files. Also, AnalookW provided the user an ability to view means from parameters mentioned in chapter I. I visually compared the selected calls identified by BCID and Echoclass with known pulses from the Midwest Call Library. Also, using these data, time of greatest bat activity was ascertained.

Unknown call files are normal in Echoclass. Again, program R was used to randomly select 50 unknown call files for visual identification. The number of pulses will be counted and if the call was identifiable, based on call parameters or visual comparison, a species level identification was given.

Fatality Searches

Searches for bat fatalities were performed on two consecutive days every week. To increase searcher efficiency, my technician and I performed double-grid searches. During these searches we used a 20-m^2 grid centered on the turbine, with transects 1 m apart. Transects were walked slowly and thoroughly north-south and then east-west. To avoid double-counting a carcass, we marked where the animal was with an orange flag. After finalizing our search, we returned to the marked sites for collection. The recovered carcasses were placed in a plastic zip-lock bag with the date, species identification, and at which turbine the carcass was found. For each carcass location, the distance centered on the turbine was measured and an azimuth was taken from the center of turbine.

Searcher Efficiency

Efficiency of the searchers was tested 7 separate times at the end of the 2013 season (17 July 2013-02 Sept. 2013). To estimate searcher efficiency, a total of 20 bat carcasses were placed randomly at the Diaz-turbine site in locations within the 20-m^2

area of the turbine, using a random direction and a random distance. North, northeast, east, southeast, south, southwest, west, and northwest were assigned numbers from 1-7. A number, within this interval, was randomly generated for the direction of placement. This method was also performed in order to randomly retrieve a distance away from the turbine's center point. Distances of 3, 6, 9, 12, 15, and 18 were assigned numbers 1-6 and another random number was generated. For example, if the random-number generator gave numbers 3 and 5, a bat would be placed 15 meters east of the turbine's-center point. No more than three bat carcasses were placed for the searcher to recover. After the search had been performed, a person returned and checked for missed carcasses. Also, scavenger removal was tested by placing bat carcasses in areas comparable to the habitats surrounding the studied turbines. A wildlife camera was placed in the area of carcass placement. The camera was checked every time searchers performed their fatality search. Dr. Aylsworth (pers. comm. 2012), using female brown-headed cowbirds (*Molothrus ater*), stated that 25% of the birds she used for scavenger removal tests lasted no more than seven days. Further, she claimed that ~50% of the birds not scavenged lasted 25 days or longer. She found no difference in scavenger removal between the Arkansas Highlands and the Arkansas Delta. Arnett et al. (2008) found that studies using bat carcasses lasted from 2.8-12 days. Thus, scavenger removal was included in final results.

Statistics

Rayleigh's Test of Uniformity was used to test whether the fatalities at Diaz were randomly distributed. Testing the correlation of direction of fatalities and wind direction, Correlation of Directionality (CircStats Package, Program R, Lund and Agostinelli 2012) was used (R Core Team 2014). I took the azimuth from where the fatality was found and directional data from winds the week the fatality was found and used the mean weekly wind direction for testing. To test if distance from turbine fatalities were found and if wind speed correlated in distance away from the turbine I used Spearman's rank correlation.

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Chapter III
RESULTS

Turbine Production

All landowners (with the exception of the non-operational turbines at Burdette and Prairie Grove) had estimates of energy produced from 2013 (Table III.1). Fair Oaks reported production from 2012. Production numbers for Springdale turbines are published online (Pollard 2014). Dividing the estimated number and dividing annual production it by four gives an approximate value for the summer production (15 May-15 Aug.). These numbers are biased because of greater wind during the winter months (Fig. III.1). Combined energy produced by all operational turbines totaled 105,313 kilowatt hours (kWh), which establishes a total of 5% efficiency from all turbines per year.

Table III.1: Location, capacity, potential energy output, actual energy output during 2012 (Fair Oaks) and 2013 (Diaz, Ponca, and Springdale), and efficiency of all turbines in the study during the time reported. Efficiency is reported with only the four operating turbines.

Location	Capacity (kw)	Potential energy (kWh/Year)	Annual Production (kWh/Year)	Summer production (kWh/3 months)	Efficiency (%)
Burdette	50	438,000	-	-	-
Diaz	50	438,000	~87,707	~21,927	20
Fair Oaks	10	87,600	~521	~130	0.5
Ponca	10	87,600	~7,500	~1875	9
Prairie Grove	100	876,000	-	-	-
Springdale	3@2.4	63,072	~5053	~1263	8
Total	227.2	1,990,272	~105,313	~25,195	9.4

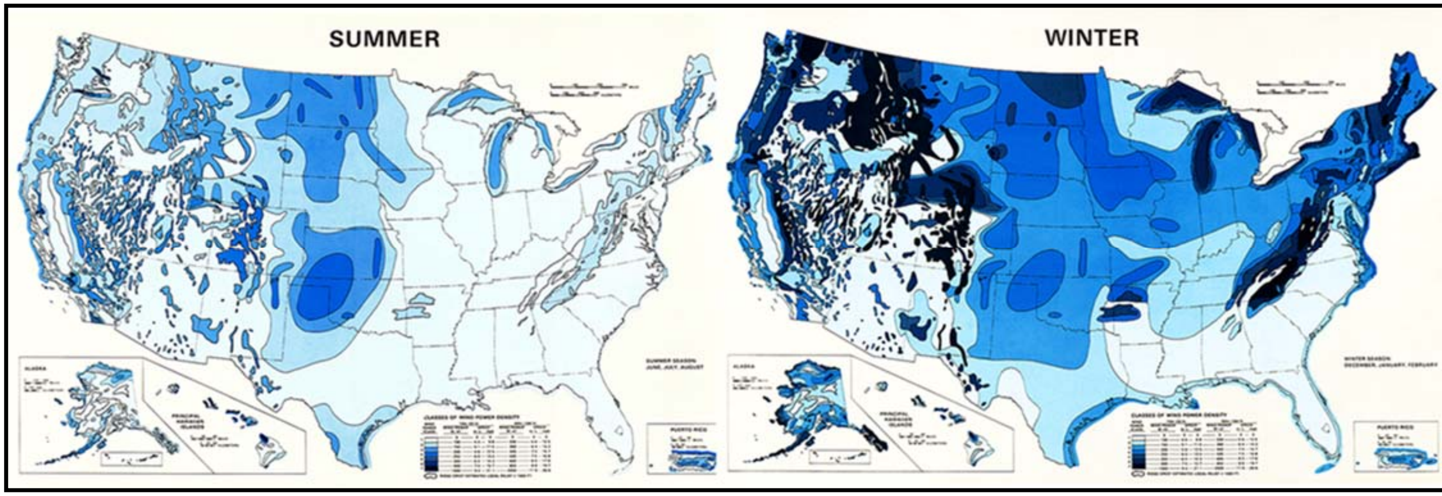

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Figure III.1: National wind resource map (WRM) for summer and winter seasons. WRM allows project leaders to identify where winds are strongest before the establishment of a large-scale wind farm. Stronger winds are found throughout the state of Arkansas during the winter months than in the summer months. High winds are reported in the Ozark Plateau during the winter. Wind resource map developed by PNNL 2010.

Landscape and Site Description

Only one of the six sites is a forested landscape. Four of the six sites have water resources within 2 km of the turbine and all sites have cleared foraging areas. All sites within the Delta region are identified as agriculture. Sites in the Karst region were identified as one forested and two urban.

Mist-Net

During 2012 and 2013 netting efforts totaled 30 net-nights (one or two nets per site per night) and 150 hour. A total of 94 bats (Table III.2) were captured comprising of nine differing species (Table III.2). Due to lack of netting locations in Fair Oaks (landowner removed himself from study after the first year) and Springdale, sites were not netted during the two years of netting effort. Additionally, the Ponca location two big-brown bats, an eastern small-footed bat, and two northern long-eared bats (all living) were retrieved from the land-owner's house during day-time hours.

Table III.2: Bats captured per netting location, total captures, and total net nights during the 2012 and 2013 study in Arkansas. All bats, with the exception of four, were captured in mist nets. Netting wasn't performed at Springdale or Fair Oaks due to a lack of netting locations.

Species	Burdette	Daiz	Ponca	Prairie Grove
Lasiurus borealis	2	7	19	15
Perimyotis subflavus	0	0	2	8
Nycticeius humeralis	0	0	1	0
Eptesicus fuscus	0	0	2	2
Myotis grisescens	0	0	0	28
Lasiurus cinereus	0	0	0	1
Myotis austroriparius	0	1	0	0
Myotis septentrionalis	0	0	2	0
Myotis leibii	0	0	1	0
Corynorhinus rafinesquii	0	3	0	0
Total captures per location	2	11	27	54
Total net nights	6	8	8	10

Acoustics Surveys

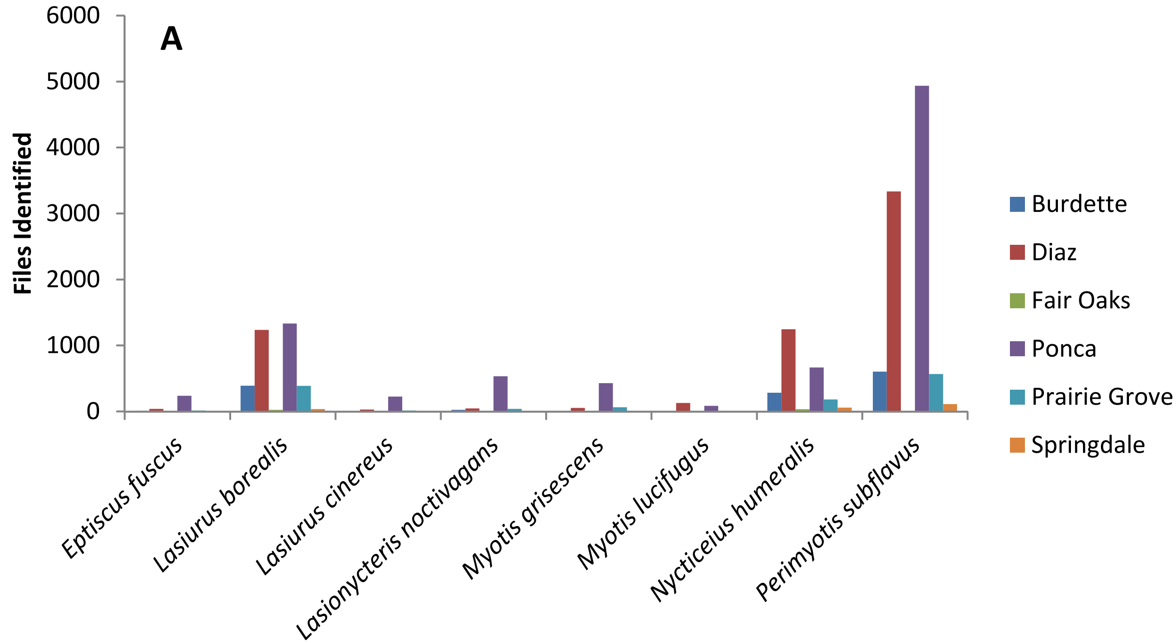
Acoustic surveys accounted for 182 days per year and 17,017 hours of survey time in the summers of 2012 and 2013. The first year of recordings totaled 9,282 hours followed by 7,735 hours during the second year. Each turbine totaled 1,547 hours of record time each year. The two years of survey time provided 159,788 acoustic files (Table III.3). Of these files BCID identified 17,978 calls representing 13 species (Fig. III.2A). Species that had less than 50 identifiable calls were removed from the resulting chart (Fig. III.2A). The removal of these identified calls were conducted because the resulting bars were not able to be seen.These included: Indiana myotis (*Myotis sodalis*) (33), southeastern myotis (*M*. *austroriparius*) (10), northern long-eared (*M*. *septrionalis*) (7), eastern small-footed (*M*. *leibii*) (2), and Rafinique's big-eared (*Corynorhinus rafinesquii*) (2). BCID identified 5,531 and 12,447 calls during the summers of 2012 and 2013, respectively. BCID identified a majority of the call files as the tricolored bat (*Perimyotis subflavus*) (45%). The program filtered out 141,810 files as noise and had 376 unknown or blank files.

Echoclass identified 157,788 acoustic files. Of those files, only 5,928 were identified to species-level. There were 40,357 files labeled as unknown. The 5,928 files identified to species were, mostly (80%), identified as eastern-red bats (*Lasiurus borealis*) (Fig. III.2B). Species identification with less than 50 identifiable calls were removed from resulting chart (Fig. III.2B). The removal of these files were done for the reasons mentioned above. These included: northern long-eared (15), Indiana myotis (5), and southeastern myotis (1). Visual comparison to known-call sequences showed that there was a 0.74 probablity of Echoclass correctly identifying species-level call sequences. There were 17 cases in which eastern-red bats were misidentified as tricolored bats. Echoclass removed 111,344 files that were identified as noise.

Increase in Anabat recordings were seen in from 2012 to 2013 data at Diaz (32 %), Ponca (90 %), and Springdale (89 %). Decrease in recordings were found at Burdette (32%) and Prairie Grove (62 %) from 2012 to 2013.

Table III.3: Acoustic results by location with the probability that BCID would identify the sequence with no filters applied. Probability of ID is the programs likelihood that an identification was made from the files recorded.

	Files per year			
Turbine Location	2012	2013	Calls Identified (BCID)	Prob of ID
Burdette	3661	2465	1326	0.22
Diaz	15113	22271	6254	0.17
Fair Oaks	433	0	64	0.15
Ponca	2821	28860	8719	0.28
Prairie Grove	43930	16674	1325	0.02
Springdale	2465	21095	243	0.01
Total	68423	91365	17978	0.13



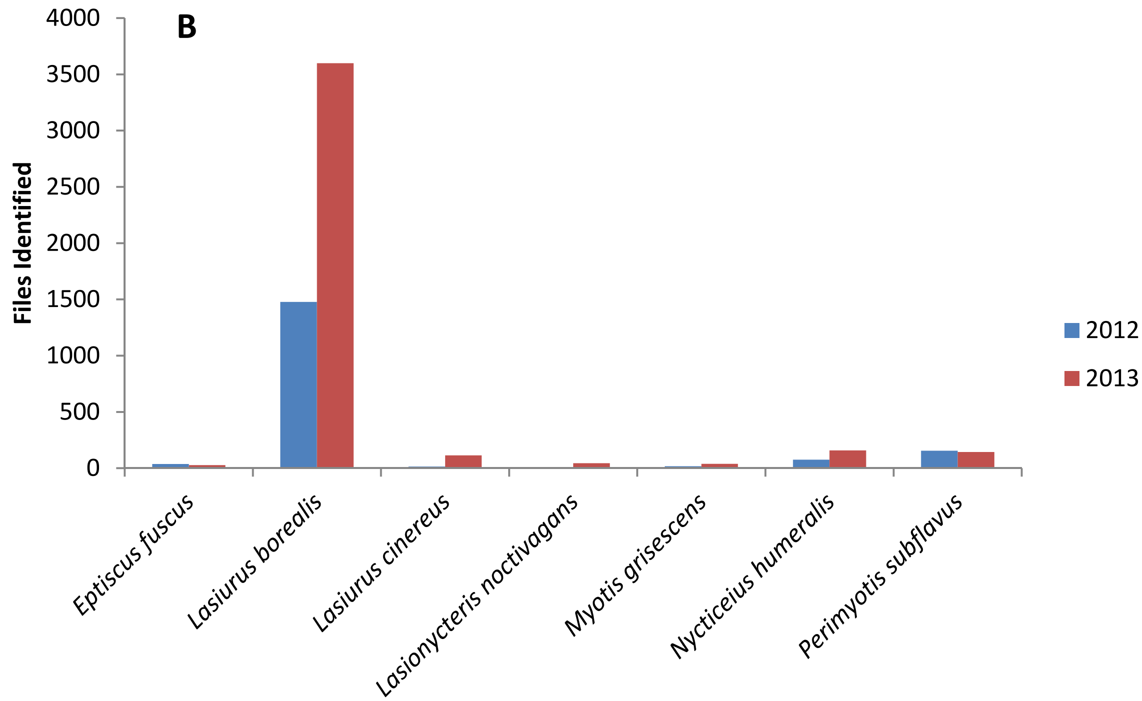


Figure III.2: A) Bar graph of BCID identification for all locations over the two year survey period. *P.* subflavus was identified most often B) Files identified by Echoclass v.2 at all turbines over the two years of surveys, *L. borealis* was identified most often.

Acoustic Analysis

A threshold of ≥ 10 pulses and ≥ 0.85 discriminate probability were used for visual analysis. BCID identified 1,385 call sequences meeting the above criteria out of the possible 17,978 calls. Of the 1,385 sequences, 1,357 were identified as the tricolored bat (Fig. III.3). The remaining 28 sequences meeting these criteria, consisted of 12 silver-haired bat sequences (*Lasionycteris noctivagans*), 11 hoary bat sequences (*Lasiurus cinereus*), and one sequence for each of the following: big-brown bat (*Eptesicus fuscus*), evening bat (*Nycticeius humeralis*), Gray bat (*Myotis grisescens*), Indiana bat, and little-brown bat (*M. lucifugus*). Program R (R Core Team 2014) was used to randomly choose 72 tricolored sequences for visual comparison, while all other sequences meeting the above criteria were included, totaling 100 sequences (Appendix 1). Visual comparison resulted in 65 positive identifications of tricolored bat sequences and 25 of 28 positive sequences for the remaining identifications. BCID misidentified high-frequency static (biological or anthropogenic) as a silver-haired bat (Fig. III.4), a big-brown bat sequence was identified as a hoary bat sequence, and a little-brown bat sequence was misidentified (visual confirmation could not be made). A 0.90 probability of correct identification was found for the criteria set above. Of the 50 unknown calls randomly selected from Echoclass, 25 were identified to species, three were static, and the other 22 were unidentifiable (< 5 pulses per unidentifiable call).

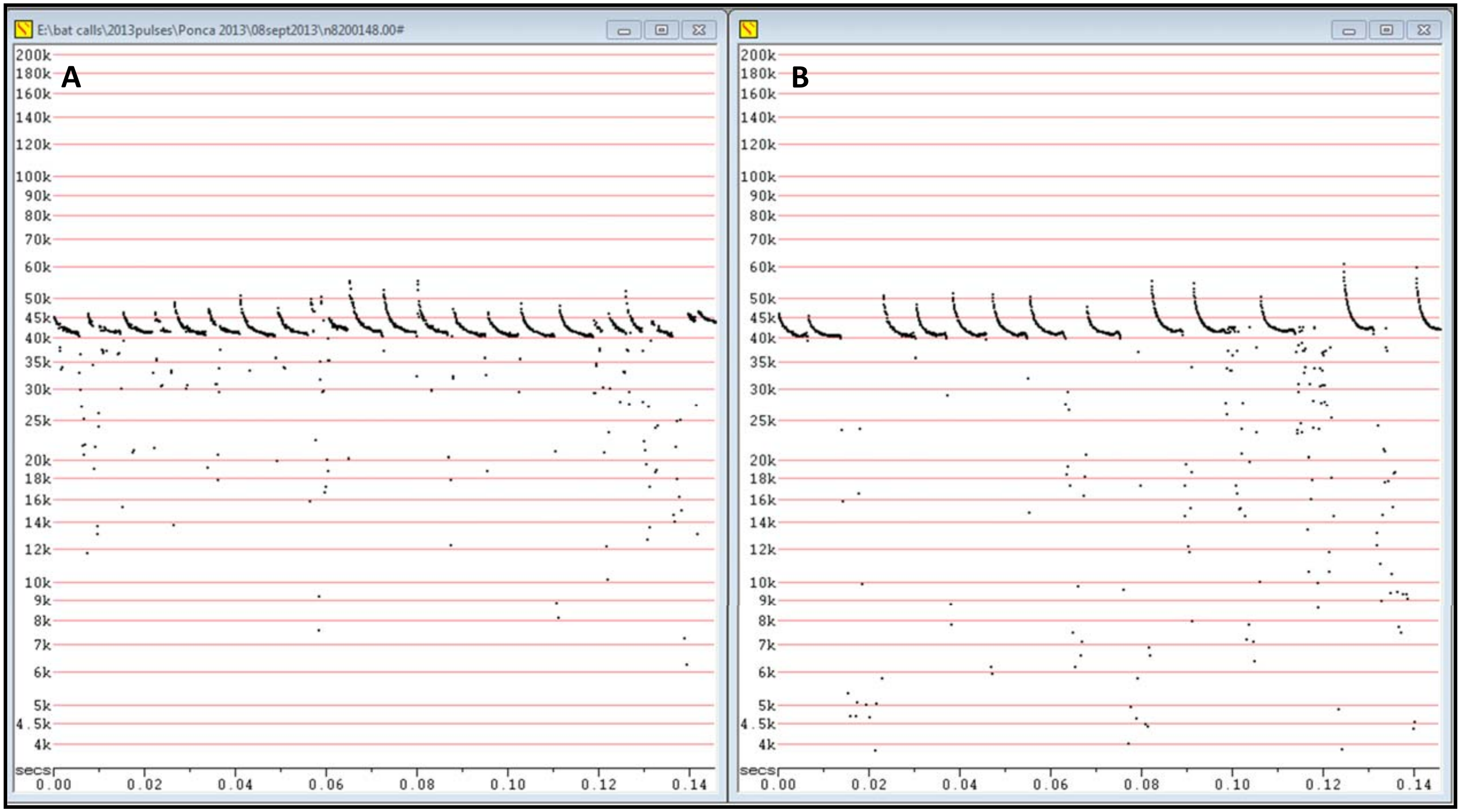


Figure III.3: A) An unknown bat-call sequence identified by BCID as a tricolored and visually confirmed as that species. B) Known tricolored bat (*Perimyotis subflavus*) call sequence (Murray et al. 2001). A noticeable difference in time-between-calls can be seen, other aspects of these calls are similar. F_{max}, F_{min}, F_{slope}, and Slope change all tend to be within range of each other.

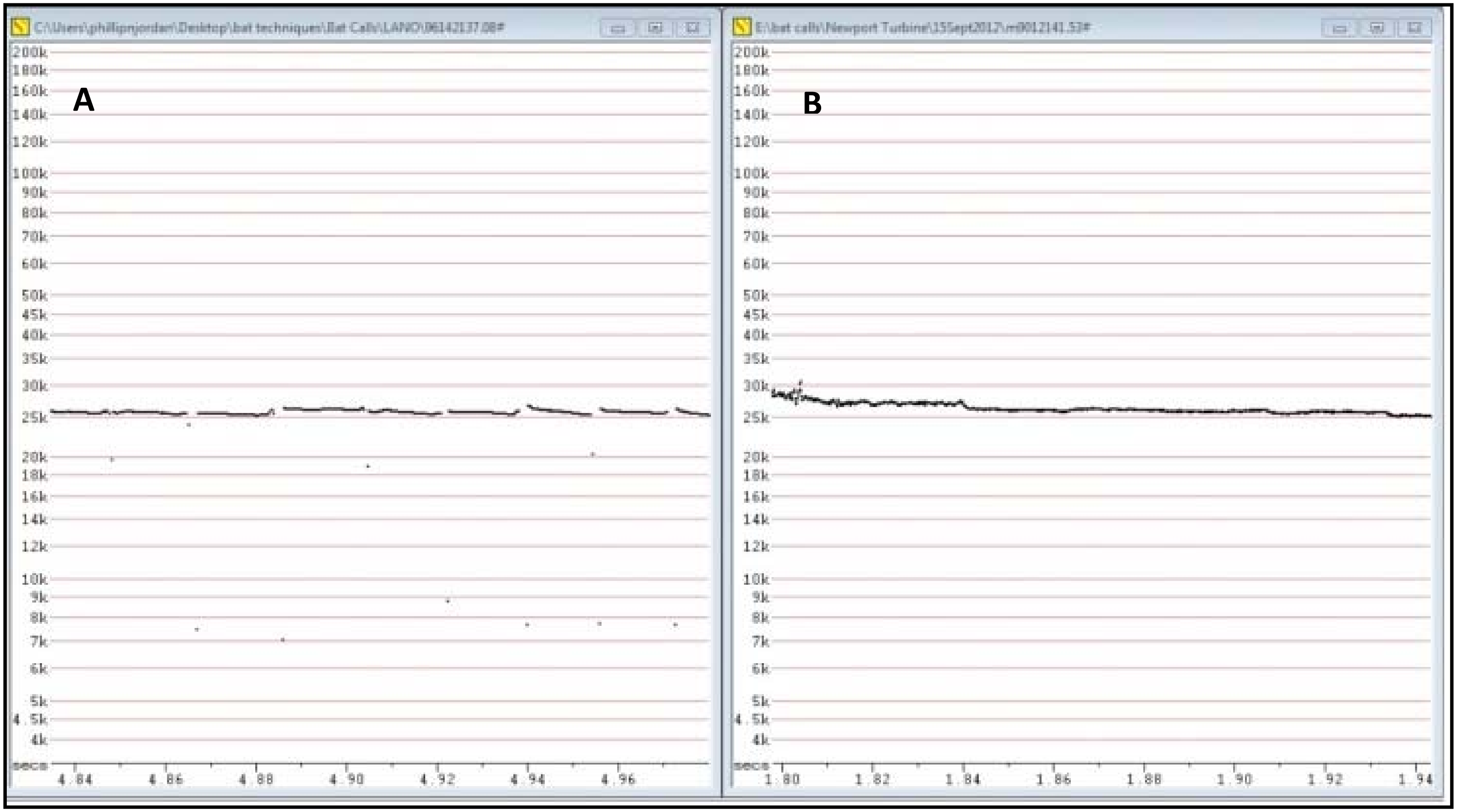


Figure III.4: A) A known silver-haired bat (*Lasionycteris noctivagans*) search-call sequence from the Mid-West Call Library (Murray et al. 2001). B) Static ranging from 25-30 kHz that was identified by BCID as a silver-haired bat (0.88 probability). Little evidence, in this study, suggests this program does not make erroneous identifications from static very often.

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Activity was consistent throughout the nights of survey (n= 45,780 acoustic files from Echoclass). The peak-activity time was between 21:30 and 21:40 (Fig. III.5).

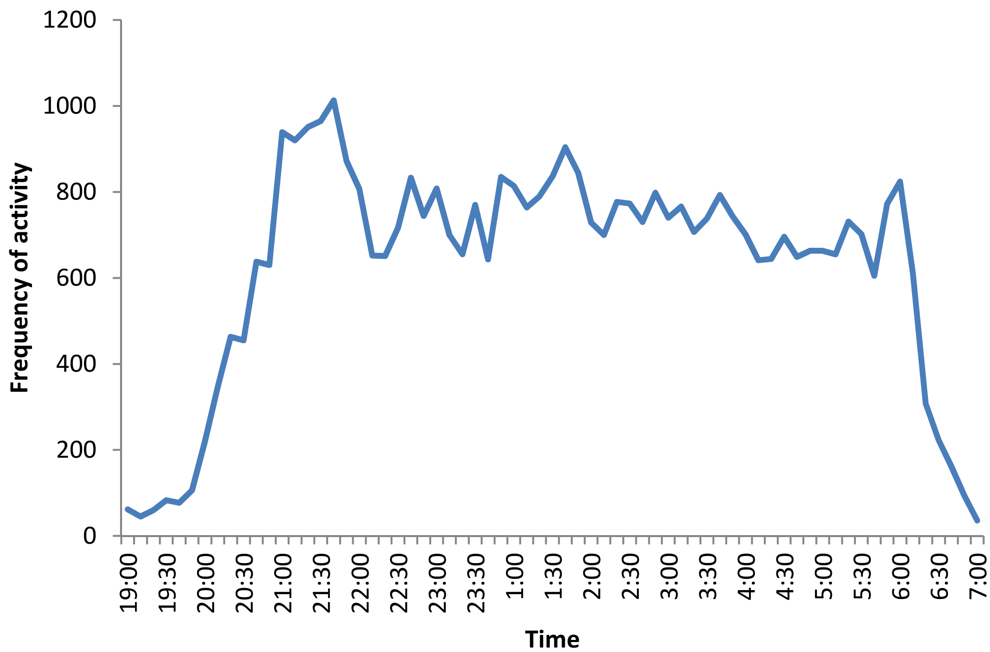

Figure III.5: Nightly activity of 45,780 bat sequences from the surveys of 2012 and 2013 as recorded by the dectector. The time of greatest activity was from 21:30 to 21:40. Times from 23:40 until 01:00 were removed due to Microsoft Excel reading times from 00:00-00:59 as numerical data instead of time data. Time stamps from Echoclass v2 were used in this chart.

Fatalities Search

A total of 64 searches were performed on the Diaz turbine (32 searches per summer). A total of 20 bats (Fig. III.6) were found within 20 m of the Diaz turbine: 18 *L. borealis*, one *L. cinereus* (Fig. III.7), and one *P. subflavus*. There was a 30% chance of finding a dead bat at this turbine per visit. The direction of fatalities was randomly distributed (t = 0.0766 p=0.8916, n=20). Correlation of directionality (CircStats package, Program R, Lund and Agostinelli 2012) between mean weekly-wind direction (week of fatality finding) and direction of fatality was not significant (t=0.582, r=0.129, p=0.560) indicating mean weekly-wind direction did not contribute to the direction of where the bat fatalities were found. Also, Spearman's rank correlation established no link between mean weekly-wind speed and fatality distance (rho= -0.303, p= 0.194).

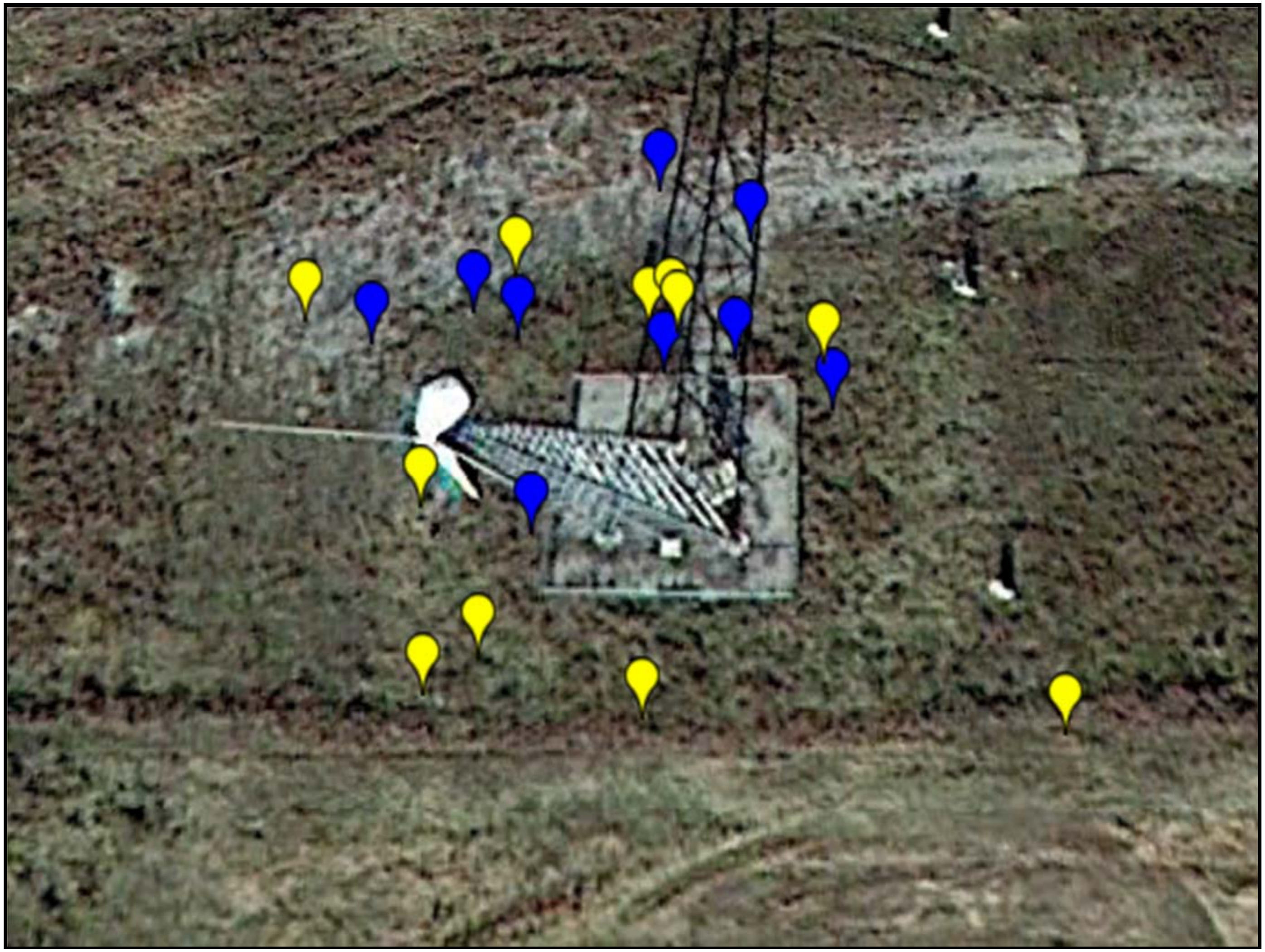

Figure III.6: Image of Diaz turbine and actual fatalities from two years of surveys. Yellow points indicate 2012 fatalities; blue points indicate 2013 fatalities (Google Earth 2012). Wind direction and speed didn't not contribute to the point of where fatalities were found.

Figure III.7: Image of a hoary bat (*Lasiurus cinereus*) carcass found at the Diaz site in 2013. The bat was found 16 m north of turbine in a gravel portion of our search area. The carcass was not moved until after the picture was taken.

Burdette, Ponca, Prairie Grove, and Springdale turbines were surveyed twice a week every two weeks, totaling 48 searches over two years. During the first search (18 May 2012) of the Springdale site, I found one blue jay (*Cyanocitta cristata*) under a tree ~ 18 m east of the turbines and one common snipe (*Gallinago gallinago*) ~ 10 m west of the turbines. A visible break in the blue jay's neck indicated cervical dislocation as a cause of death, whereas the common snipe was severely decomposed and cause of death could not be determined. At Ponca (26 July 2012), I found a deer mouse (*Peromyscus maniculatus*) ~ 10 m from the turbine. During a routine discussion with the land owner, it was mentioned that he had found and killed this deer mouse and threw it near the turbine. Zero bat fatalities were discovered at these four turbines during the two seasons of study.

Searcher Efficiency

During this phase of the study, the searchers found 16 of 20 carcasses suggesting a 0.80 probability of finding any bats that could have been struck by the turbine. Scavenger rates were observed during this study. Many samples of animal scat that included fragmented bones and fur were found. The bone and fur were not identified. The scat included samples from coyote (*Canis latrans*), raccoon (*Rocyon lotor*), and Virginia opossum (*Didelphus virginiana*). No animals were captured on camera during the game camera time period.

Accounting for searcher efficiency (Hayes 2013, Smallwood 2013) and assuming zero scavenging, an estimation of bats mortality during the two years would be 24 bats. This number is derived with equation F_a*S_e=M_m, M_m+F_a=M where F_a= actual two year total, * S_e= Searcher efficiency, M_m= missed mortality, M= possible two year total. Using the equation above, 4 bats would have been missed, adding this to the observed mortality.

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CHAPTER IV
DISCUSSION

Single-Unit Turbines Effects on Bats

During the two summers of study (2012 and 2013), the Diaz-turbine site killed 20 bats while producing ~ 42,854 kWh of energy. A small proportion of bats were killed per kWh (0.000466 bats/kWh) over the two years. All four turbines produced an approximate 50,390 kWh during the two years of summer searches. Using the estimated 24 fatalities for all turbines combined, there is a probability of 0.0004762 of a small-unit turbine killing a bat per kWh produced. This is greatly reduced from large-scale facilities like Mountaineer with an average of 47.5 bats per turbine (Kerns and Kerlinger 2004), Buffalo Ridge 2.0 bats per turbine (Johnson et al. 2003), and Buffalo Mountain 3.0 bats per turbine (Fielder et al. 2007) found during a one-year period. The probability of a 1.5-MW turbine, that produces approximately 4204.5 MWh (32% efficiency) at Mountaineer, WV killing a bat is 0.011 per MWh or ~1 bat per kWh.

Although none of the bat carcasses found was an endangered bat species, a tricolored bat (*Perimyotis subflavus*) was found on 17 July 2013. This species has experienced mortality thoughout its range due to the fungus *Pseudogymnoascus destructans* causing a disease known as White-Nose Syndrome. This species has been listed as threatened or endangered in many Northeastern and Central states (Michigan

State University 2009, Davenport 2013, McKnight and Brewer 2013, Kaarakka et al. 2013). As of 2011, the USFWS has petitioned biologists to collect more information on this species before possibly listing it as endangered.

The bats around the turbine in Diaz are at quite a disadvantage. Many factors are to consider, to explain that it was the only turbine with observed fatalities. There are four rivers within 20 km of the Diaz turbine (Fig. IV.1).

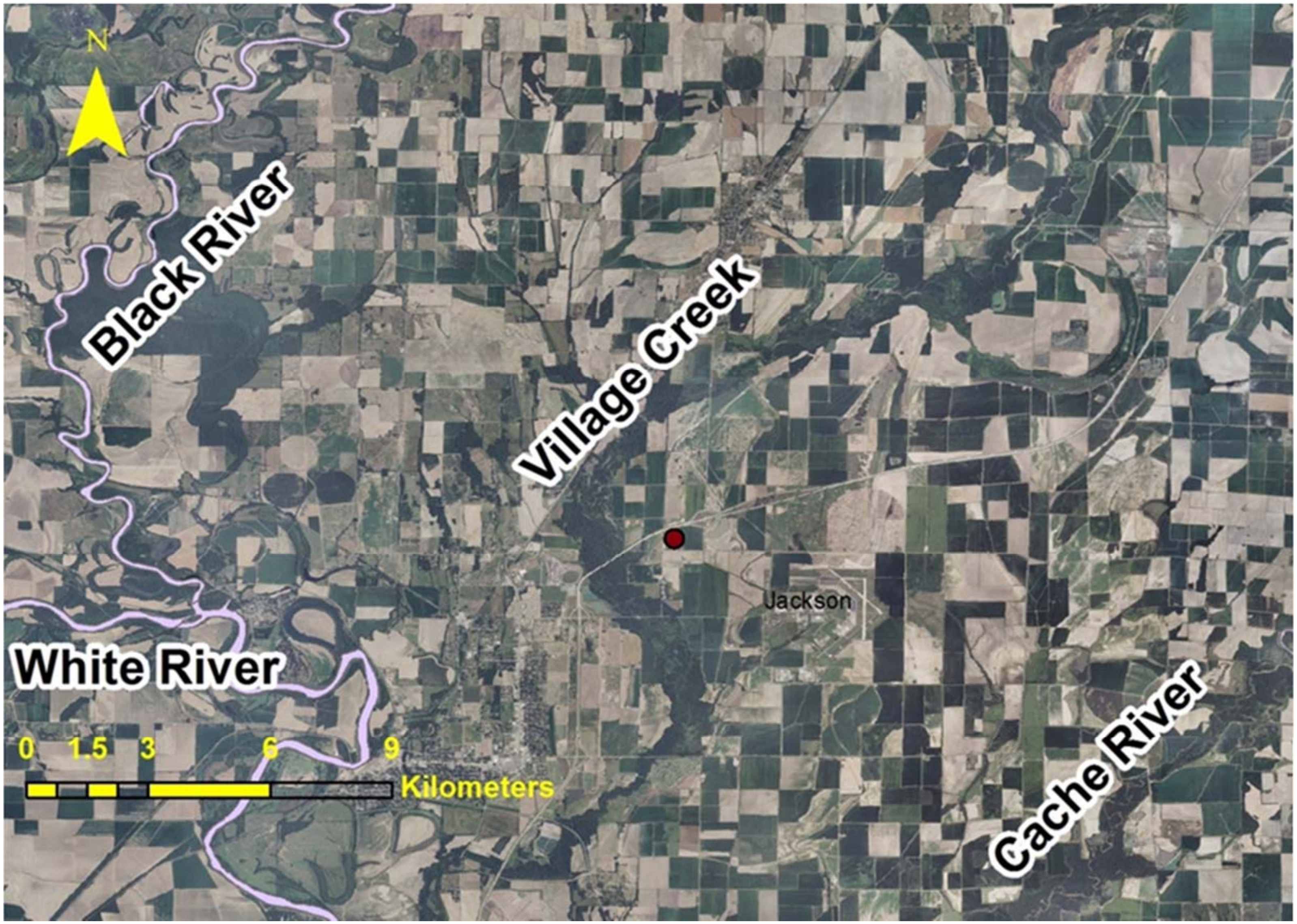

Figure IV.1: Aerial view of the surrounding landscape around the Diaz turbine and the four rivers near the location. Each river could have acted as a flight corridor contributing to the local population around the study site.

The Black River is located 7.62 km west of the turbine, White River runs 6.89 km southwest of the turbine, Village Creek (a tributary of the Black River) is 1.28 km from the turbine site, and finally Cache River which is located 14.25 km east of the turbine. Intermixed between these rivers are numerous hectares of agricultural-crop lands. Many of these crops harbor insects that bats find attractive as food sources (Agosta 2002, Wickramasinghe et al. 2004, Lee and McCracken 2005, Cleveland et al. 2006). Also, a major highway (Hwy. 67) is located 50 m north east of the turbine. Road-ways provide a linear flight path (Russel et al. 2009) and car lights are an attractant for bat prey (Berthinussen and Altringham 2012). These could be some possible reasons for the mortality events at Diaz. In Poland, areas where a tree line was perpendicular to the road, many bats were found mortally wounded by vehicle collisions (Lesiński 2008), although Kitzes and Merenlender (2014) found that as distance from the road increased, so did bat activity. On 19 June 2012 and 3 July 2013, several hundred bats were seen flying low and erratically over Hwy. 67. A migration hypothesis to explain large aggregations of bats around the highway is unlikely because the time period this event was seen, was not during the migration period (spring and fall) (Cryan 2003, Fleming and Eby 2003, Cryan et al. 2004). The month with greatest activity during the 2013 at Diaz was July. Considering that migration occurs during spring and fall July would seem to have a depressed activity compared migration periods (Fig. IV.2).

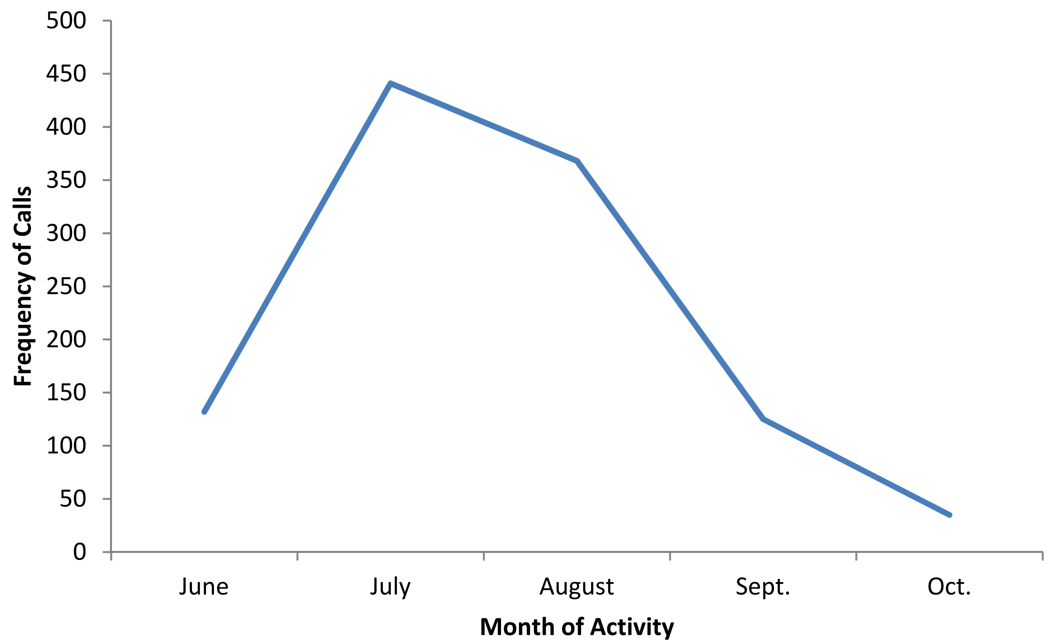

Figure IV.2: Calls from the Diaz turbine (2013) identified to species by Echoclass v2. Monthly activity increased sharply from June to July. A slower decrease was seen during the latter portions of the summer. All unknown call files were removed.

An alternative hypothesis could be an insect emergence with vehicle lights acting as an attractant. A third explanation for this high bat mortality at Diaz is the size of its rotor-swept area (Arnett et al. 2008). The rotor-swept area for the Diaz turbine is 293 m^2 compared to the others which are ≤ 40 m^2 in area. Anabat activity was comparable at the Ponca (28,860 files) and Diaz-turbine sites (22,271 files) in 2013, yet no bats were found mortally wounded at the Ponca site. The tower structure is the same (lattice self-supporting) there is a water source and wooded areas close to each turbine site. This lends support to the hypothesis that larger rotor-swept area equals more fatalities. These hypotheses could not be tested due to the small-sample size (one turbine had fatalities).

A possible indication of the turbine causing mortality events is during shutdown periods (lighting strike, seasonal maintenance, etc.). Anabat activity at the Diaz site remained consistent with pre-shutdown activity, but fatalities were no longer found. Also, Anabat activity was not disrupted due to vehicular traffic. Vehicular traffic is assumed to be approximately the same throughout turbine-shutdown time as it was before the turbine was shut down. Although traffic remained the same, fatalities were no longer found during shutdown. These shutdown events happened in both years at the Diaz turbine.

Barotrauma is also a suspected source of bat fatalities at large wind farms. Barotrauma is caused by a sudden drop in pressure causing tissue damage to areas such as the lungs (Baerwald et al. 2008). Although a suspected source of mortality, barotrauma is disputed as a significant cause of bat mortality (Grodsky et al. 2011, Houck 2012, Rollins et al. 2012). Barotrauma cannot be ruled out as a cause of death at the Diaz turbine. Although evidence exists from turbine strikes being the cause of death (two eastern-red bats found with a broken humerus which is not consistent with a fall; Grodsky et al. 2011), most fatalities found were too decomposed by the time searchers found them to determine, with certainty, the cause of death. As predicted, 95% of bats killed at Diaz-turbine site were species of forest bats (eastern red bat and hoary bat).

The amount of scat seen at the beginning of each year could be attributed to scavengers eating wounded bats and leaving scat behind. It could also indicate that animals scavenged off the highway and use the turbine area as a resting area (Santos et al. 2011).

Acoustics

The ability to record vast amount of echolocation information from acoustic detectors has advanced our ecological knowledge of a cryptic animal. Advances in knowledge of foraging behavior, echolocation while foraging (i. e., search and clutter pulses, feeding buzzes), the frequencies at which different guilds emit, and many other advances have been reached with acoustic detectors (Fenton and Bell 1981, Jones and Rayner 1989, Griffith 2013, Müller 2013). Although, this information is useful, limitations such as analysis of large groups of data, data storage, costs, and a wide range of echolocation calls also exist with the technology (Fenton 2002, Obrist et al. 2004, Artimage and Ober 2010, Szewczak 2013).

Analysis of these data is very time consuming and is not practical. Thus, automated programs are relied upon to interpret these vast storages of calls. Bat Call Identification (Allen 2010), Echoclass (Britzke 2012), and Kaleidoscope (Wildlife Acoustics 2013) are a few programs available commercially for identification of stored data. One program can give very different results from another. For example, analysis from BCID resulted in 35% more calls identified over Echoclass, even though many of the BCID results showed low probability of having the correct identification. Echoclass had ~ 99% more unknown-call files than BCID. Echoclass is a conservative program. If a call sequence has calls attributed to differing species or if feeding buzzes are identified, the sequence is then labeled unknown avoiding many false-positives (Britzke et al. 2011).

BCID East uses an analysis system known as CART (Classification and regression tree analysis) (see Morgan 2014 for description). The use of this system entails binary predictors (i.e., 15-25 kHz or 30-45 kHz). The finding that best fits that particular predictor is kept, given a weight, and the next predictor is tested (F_{max}= 45 kHz or F_{max}= 35 kHz). After testing all predictors/parameters (outlined in Chapter 1), the species best fitting all parameters is chosen by the program and given a discriminate probability. The discriminate probability is how likely the program is correct in its identification. Echoclass uses discriminate function analysis. Anomalies are found when looking at species that have similar values in each parameter tested. For example, the tricolored bat, evening bat, and eastern red bats are labeled as a mid-frequency bat (search call 35-45 kHz, clutter calls and buzz feeds are found up to 100 kHz). The red bat has an F_{min} for search calls of ~ 35 kHz, but often they have search calls with F_{min} between 40-45 kHz much like the tricolored, the same can be found with F_{max} (Fig. IV.2).

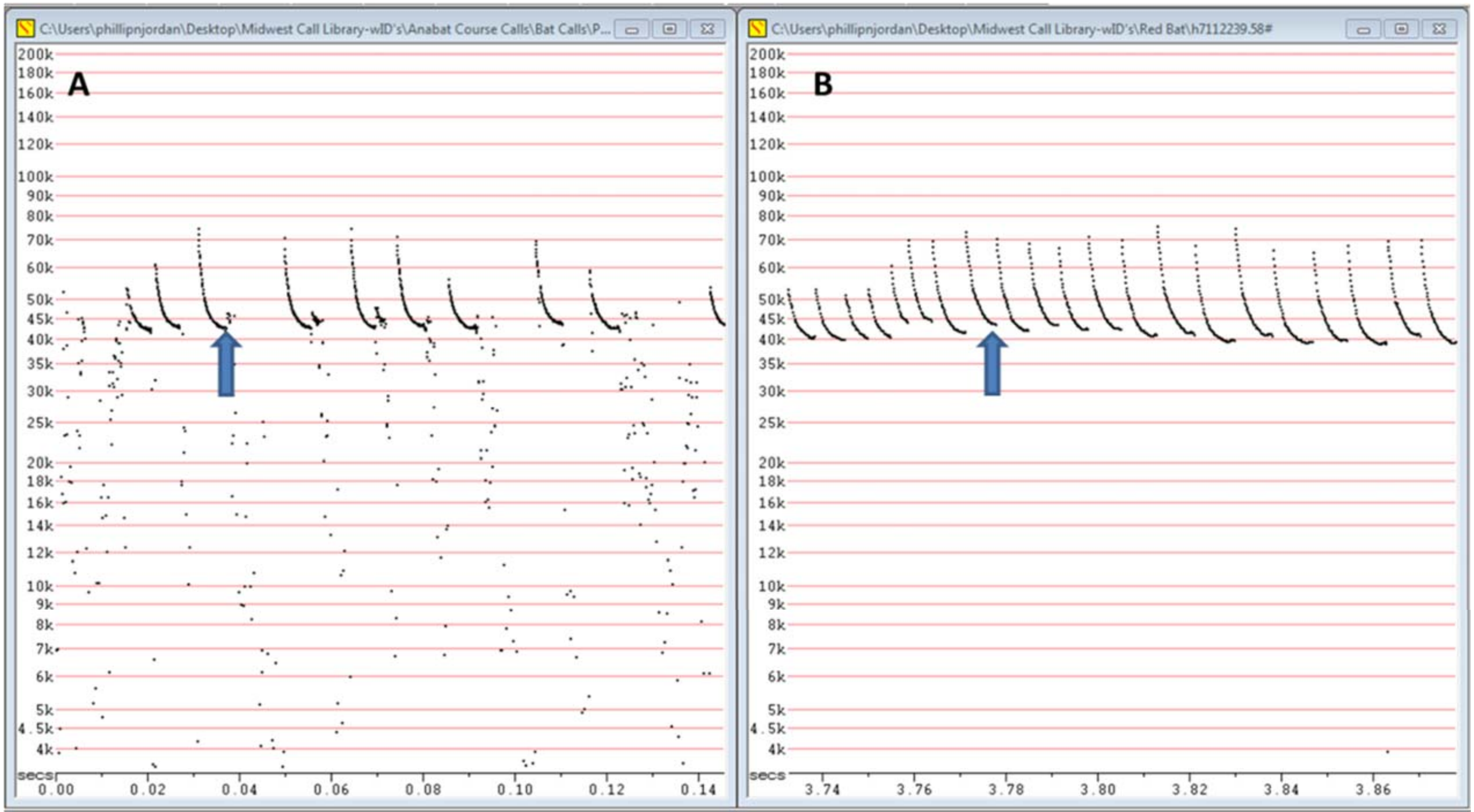

Figure IV.3: Similarities in tricolored bat and Eastern-red bat pulse sequences. A) Tricolored bat echolocation sequence. B) Red bat echolocation sequence. The pulses indicated by the blue arrows identify pulses that have similar frequencies in each parameter. The two species both calls were retrieved from Mid-west Call Library (Murray et al. 2001).

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Many species in the genus *Myotis* also have similarities in their call structures. The little-brown, Indiana, and the northern long-eared (*M*. *lucifugus*, *M*. *sodalis*, and *M*. *septentrionalis* respectively) have many similarities in call structure (Fig. IV.3). Each of these three species calls (search or feeding buzz) can have F_{max} > 100 kHz, F_{min} ≥ 40 kHz, F_{knee} between 40-45 kHz, and TBC (time between calls) being similar.

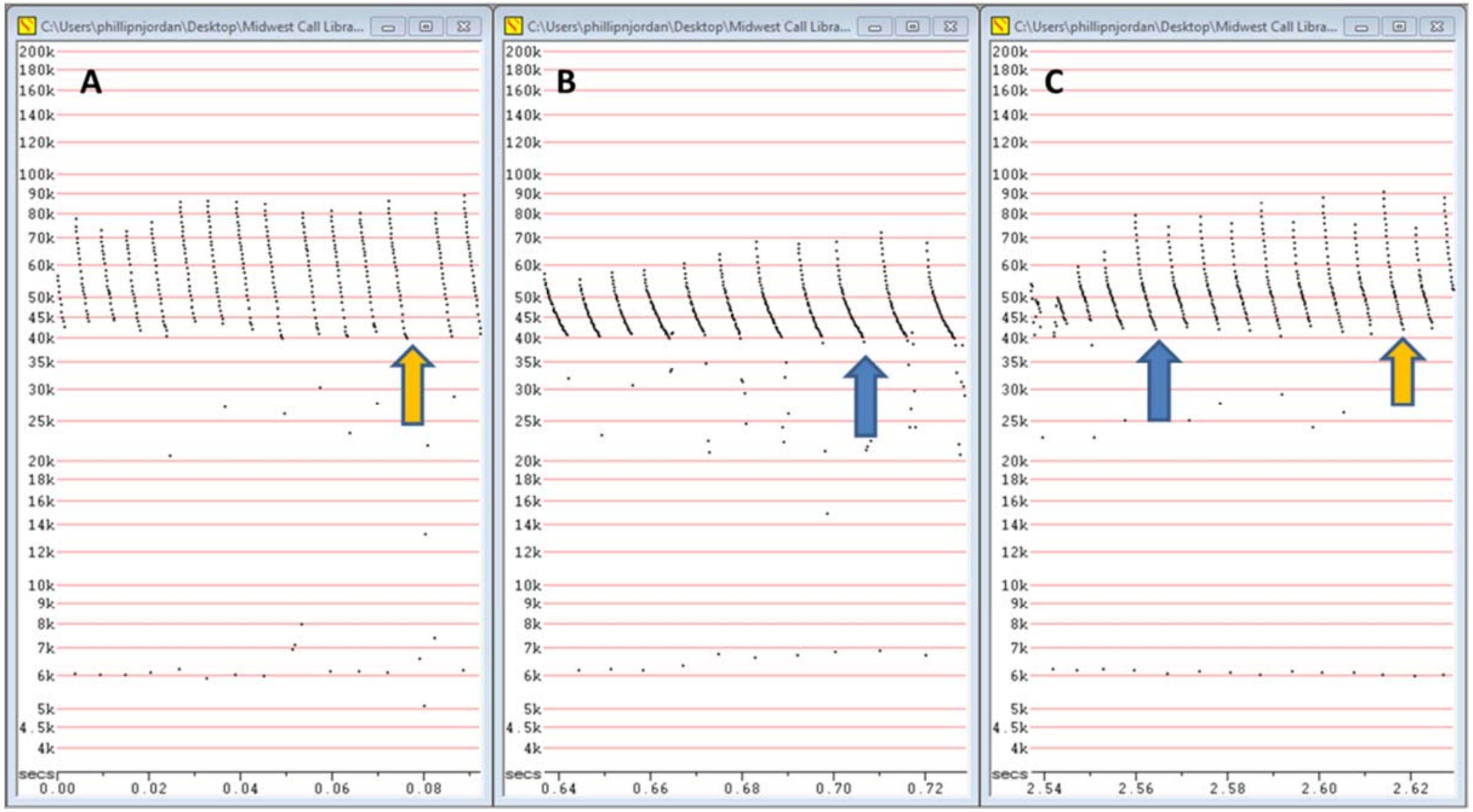

Figure IV.4: A) Northern long-eared bat B) little-brown bat C) Indiana bat. Indiana bat has similar pulses as the northern long-eared bat (yellow arrows) and little brown (blue arrows). Many aspects of these calls are similar and both programs had difficulties in identifying calls of these nature. All are from the *Myotis* genus.

BCID identified 17,978 call files as being attributed to a specific bat species. Of these call sequences 1,385 met the threshold previously established. The species attributing to most of these calls was identified as the tricolored bat (98%). All turbine locations had calls meeting this threshold, but most (85%) were from Diaz and Ponca turbine. This is inconsistent with other data obtained from these turbine locations. The tricolored bat represented 11% of mist-net captures, while the red bat was 45% of bat captures. The same follows with fatalities at the Diaz turbine, 90% of bats found during the two years of surveys were eastern-red bats. Even though these results coupled with results from Echoclass show that the red bat was dominant in these particular areas, BCID labeled tricolored as being the predominant species. Although the 72 randomly chosen calls were visually confirmed to be correct with 0.90 probability, the likelihood of tricolored activity being greater than red-bat activity is very low considering supporting data, like captures and fatalities.

Increases in Anabat recordings and mist-net surveys were seen at three locations between the 2012 season and the 2013 season. This increase in activity could be weather dependent. The 2012 season was hot, humid, and dry (driest year on record), whereas 2013 was more mild and wet. During 2012, the month with the most rain was during March when 14.73 cm of rain was reported. The most rain captured during the summer was on 7 July when 4.83 cm rainfall was recorded. The day with the highest temperature was recorded on 28 June with a value of 41.7˚C and the month of July averaging 35.6˚C. For 27 consecutive days in summer 2012, temperatures were above normal. The 2013 season was considerably different. May was the wettest month of the year with 45% of days seeing precipitation. The day with the most rain was August 8 when 19.71 cm was recorded. The hottest day was June 27 when a high temperature of 36.7˚C was recorded. The hottest month was in July when the average was 30˚C. Changes from season to season were dramatic. A pond in Ponca that is 21.8 m wide and 50.3 m long was nearly dry during the 2012 season. The rain and mild temperatures during 2013 caused the pond to stay completely full. This can be seen from year to year in the Anabat activity and mist-netting captures recorded at the Ponca location during 2013. Anabat activity increased 90% and mist-netting captures increased by 22 bats from 2012 to 2013. The contrasting decrease in Anabat activity at the Prairie Grove turbine during the two seasons can be attributed to insect, anthropogenic, or static noises. During the 2012 season the grass at the Prairie Grove location was approximately 1.5 m tall. Tall grasses are more inviting to insects (Kruess and Tscharntke 2002), which caused an increase in the number of files recorded. The landowner gave the lawn more attention during the 2013 season, thus reducing Anabat activity. There was an 89% increase in Anabat activity at the Springdale turbine site from the year 2012 to 2013. This increase in activity is due partly to insect activity, but it is also due partially to effects of water on the Anabat microphone. Condensation formed on two microphone bases, which caused disruption and static to be recorded for most of the 2013 season. Increases or decreases in activity levels at the other turbines can be attributed to local fluctuation of bat activity.

Time of greatest activity was between the hours of 21:00 and 22:00 supporting a hypothesis postulated for differences in emergence times that pertains to predation risks and associated peak insect activity (Duvergé et al. 2000). Mean time of sunset during the two years of surveys was 20:12 (Edwards 2014). Smaller aerial-hawking insectivorous bats emerge to forage ~ 15-30 minutes after sunset (Rydell et al. 1996) due to their dependence on smaller insects that are at peak during lowlight hours. Other bats that do not rely on these smaller insects emerge from roost approximately one hour after sunset (Lacki et al. 2007). The greatest amount of activity would be expected during the times found. This would suggest that smaller bats are feeding, as larger bats are beginning to emerge.

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CHAPTER V
CONCLUSION

The use of small-unit turbines is a solution to America's energy independence and reducing the use of fossil fuels. In return we are helping our world by reducing the effects of climate-changing molecules. At what cost should we continue these efforts? We have known for many years now that wind turbines cause bat mortality (Hall and Richards 1972). It was not until recent that we found wind turbines killing more bats than what we once had thought (Johnson et al. 2003, Arnett et al. 2008, Hayes 2013, Smallwood 2013). This problem has brought many scientists to study how to circumvent these dilemmas. Suggestions like increasing cut-in speed (Baerwald et al. 2009, Arnett et al. 2011), shutting turbines down during migration periods (Drouin 2014), better placement of wind-energy sites (Kuvlesky et al. 2007), and curtailment during certain weather conditions (Arnett et al. 2008) have been made. These proposed suggestions will be hard to sustain because of the high cost of wind turbines. If a facility is shut down during specific times, then the company will be losing production time. Although this will be a fear of the wind-energy sector, shut-down times will only cut production by < 1% (Arnett et al. 2011). A proposed ultrasonic-deterrent device has been shown to deter bats from treated areas, yet the range of emitted signals cannot cover the rotor-swept area encompassed by large-scale turbine blades (Szewczak and Arnett 2013). Proposals such as the ultrasonic deterrent and turbine placement will be high priorities in the future studies of turbines and mitigation strategies. Solutions are continually being sought and this study was part of that search. With populations declining at rates never seen before, solutions must be found and they must be found quickly. Following are recommendation about turbine placement, configurations, implications, and recommendations about future wind-turbine projects in Arkansas.

Placement

Recommendation on turbine placement has been suggested for the curtailment of bat mortality (Arnett et al. 2008, Georgiakakis 2012, Minderman et al. 2012), although placement on the landscape might not be a significant factor in bat mortality (Berthinussen et al. 2014). Placement could be a contributing factor to the Diaz-turbine site fatalities. Four-large riparian corridors were within 14.5 km in all directions, large-agricultural farms inviting would-be prey, and a major highway attracting prey all could have contributed to mortality. The Burdette turbine is made by the same manufacturer (Endurance Wind Energy), the supporting tower was different, the Mississippi River is 9-km east, and the area is surrounded by agricultural lands. Many attributes to the surrounding landscapes and the turbines are the same at both sites, yet Diaz had three more rivers and the major highway near it. Another major difference is Anabat activity was six-times greater at the Diaz turbine than that of the Burdette turbine. A depression of bat activity at the Burdette location could be due to an owl population within the town. An abandoned gym and an abandoned school were located ~ 330 m away from the turbine location, both inhabited by barn owls (*Tyto alba*). On one occasion, I witnessed on the ladder of the turbine tower owl pellets and abdominal portions of an animal, assumed to be left by an owl. Bats are prey of owls (Ruprecht 1978, Roulin and Chrisite 2013), yet it is suggested that bats do not alter activity level when hearing owl calls (Janos and Root 2014). Removing the possible effects from owl predation, proportionality between bat populations is greater in Diaz. The increase in activity could be because of the amount of riparian corridors near Diaz. At least in this study placement seems to be of great value.

Turbine Configuration

Although sample size restricts hypothesis testing, evidence from this study indicates larger rotor swept areas could impact bats at a greater proportion than small-rotor swept areas. Inference can be gained by a comparison between the turbines at Diaz and Ponca. Diaz's Anabat recorded 37,384 call files and Ponca's Anabat recorded 31,681 call files over the two years of study. Captures were greater in Diaz, due to more suitable netting locations. Each turbine had water sources near it, large amount of forested areas, lattice-style tower structures, and several foraging areas. Many similarities exist between these sites, with the exception of rotor-swept area. The rotor-swept areas were ~ 38 m^2 and ~ 290 m^2 at Ponca and Diaz, respectively. Although both locations were similar and bat activity was comparable, only the Diaz turbine killed bats. The fatalities at Diaz could be because the rotor sweep on the Diaz turbine is approximately seven times larger than the Ponca turbine. Many authors have suggested that rotor sweep has an effect on bat mortality (Johnson et al. 2003, Arnett et al. 2008), but some have suggested otherwise (Barclay et al. 2007, Berthinussen et al. 2014).

The style of tower could have an impact on bats. Tower style may have been compared between the Burdette and Diaz turbines if the turbine in Burdette had been operating during the time of study. The Burdette turbine had a monopole structure, whereas the Diaz turbine had a lattice-type tower. This hypothesis remains to be tested, due to shut-down periods at Diaz failing to produce fatalities during this study.

Surveys

The use of acoustic and mist-net surveys is important when discussing the placement or the effects of a turbine location on bat populations. Mist-net surveys are important in order to capture "whispering" bats. These bats are said to be "whispering" because of their low-intensity calls (O'Farrell and Gannon 1999). Of importance to my study areas are two bats that are considered "whispering" bats, the Rafinesque's big-eared bat (*Corynorhinus rafinesquii*) and the Ozark big-eared bat (*Corynorhinus townsendii ingens*). The Rafinesque's big-eared bat ranges throughout Arkansas with the exception of the Ozark Plateau (Sealander and Heidt 1990). The Ozark big-eared bat ranges in the Ozark Plateau, from the Boston Mountains and into Oklahoma (Sealander and Heidt 1990). Acoustic and mist-net surveys were of particular importance at the Diaz turbine, where I captured three Rafinsque's big-eared bat while only having a low discriminant probability of acoustic detection for this species. Mist nets play an important role in surveying for species richness (Flaquer et al. 2007). Also, netting bats can give biologists important information over the health and condition of the bats (Hayes et al. 2009). Biological information is especially important for condition assessment of bats in the summer that may have been affected by WNS during the winter (Reichard 2009).

Evidence is leading to acoustic surveys detecting species presence at a greater rate than mist netting (Murray et al. 1999, O'Farrell and Gannon 1999, Ochoa et al. 2000, Clement 2014). Contradicting the argument for mist netting, acoustic surveys reduce the handling of bats that could be infected by WNS (Ford et al. 2011). If a researcher handles a bat that is infected with WNS, the researcher could unintentionally infect other bats (Shelley et al. 2013) as the spores are very easily spread (Pannkuk 2013). Acoustic surveys also use less man power, can record typically hard-to-capture species, and if replication is of importance, sites can be easier to replicate than mist netting (Rodhouse et al. 2011).

Automatic classification software has become an effective tool for quickly analyzing acoustical data. This software should be used on a limited basis and visual corroboration of several call sequences should be made by an experienced person before results are trusted (Chenger et al. 2014).

Implications

Overall, bats only produce one to two pups every year (McCraken 1989) and six species have been found to live 30 years (Wilkison and South 2002). This gives a possible fecundity of ~ 25-30 (often less) offspring per female bat. In 2012 an estimated 5.7-6.7

million bats (Froschauer and Coleman 2012) have perished because of WNS (White Nose Syndrome) and with estimates between half to three-quarter million bats dying per year due to wind energy (Hayes 2013 and Smallwood 2013), the ability of these populations to recover from such losses is going to be difficult (Boyles et al. 2011). Thus, we could be on the precipice of bat extinctions in the United States (Frick et al. 2010). Bats are a precious commodity to the human race and should not be taken for granted. Bats provide pest control services (Boyles et al. 2011), they are excellent seed dispersers (Fleming and Heithaus 1981), and they pollinate many different species of plants (Vogel 2005, Rivera-Marchand and Ackerman 2006).

Recommendations

Mist netting and acoustic surveying should be conducted for > 45 days prior to the placement of turbines (Skalak et al. 2012) for hard to detect species. Although placement and rotor-swept areas are disputed by some authors, they seem to be a contributing factor of fatalities in this study. Until further tests can be performed, turbines with a large rotor-swept area should not be placed near areas that have high density of riparian corridors or rivers, large forested areas, and an insect attractant (highways). Also, placing turbines with rotor-swept areas near water sources that have a high abundance of bat activity should be avoided. Using large data set with automatic sequence identifiers should be used whenever possible. This suggestion allows the researcher to randomly select many call sequences for comparison against known call sequences. Having full cooperation from the landowners is immensely important for the success of studies such as this. For example, if insect noise was a problem, the landowners would cut the grass. If I needed to search the property for signs of bat activity, the owners allowed me access. The landowners allowed time for talks and discussion about certain aspects of this study.

Also, if the bat detector is being placed on the turbine-tower structure, the contact between the equipment should limited or the equipment should be grounded to the turbine. During the course of this study, two Anabats were made inoperable due to lightning strikes. The loss of recording time, money, and repair time hindered the operation of this study at two sites for one week.

Diligence among the outer limits of the search area needs to be incorporated in studies that may follow this paradigm. Although the searchers did a good job at finding most of the placed carcasses they missed the ones farther out from the turbine. If possible, start from the outside of the search grid and search while moving toward the turbine. This suggestion could eliminate deficiencies on the outside portion of the grid.

Future Studies

Unforeseen circumstances arose with the operational status of the Burdette turbine. I initially planned on comparing Burdette and Diaz turbines. Analysis of effects of tower structure, mortality in differing landscapes, and other topics could have been addressed if the operational status of the Burdette turbine had changed. Thus, securing locations that have comparable characteristics in capacity, height, rotor-swept area, etc. is of importance when future studies with single-unit turbines are suggested. The same can be said of comparable turbines from differing ecoregions. If a turbine in the karst region had attributes similar to the turbine at Diaz, statistical analysis could be performed and inferences could be made about opposing ecoregions. The use of multiple bat detectors at differing heights at all locations would also provide valuable information. Multiple detectors would allow for comparison of results from the same location on automatic identifiers, possible changes in frequency as distance from bat detector increased, and many other acoustical aspects could be tested using more detectors.

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Appendix 1. Seventy-two randomly generated tricolored pulses with discriminate probability ≥ 0.85 and ≥ 10 pulses. Twenty-eight other species-identified calls meeting the threshold were also included. All identifications were made by BCID. File name addresses which file the program identified, spp. defines what species the program attributed to the file, group identifies what guild the frequencies are in, GR Percent indicates how many pulses are within the guild frequencies, TotPulse is how many pulses the program read in the file, and DISCPROB is a determination on how well the program identified the file. All files are stored on two hard drives and a laptop computer.

FILENAME	SPP.	GROUP	GR PERCENT	TOT PULSE	DISC PROB
N7210536.57#	PESU	MID	100	25	0.950443
MA151908.54#	PESU	MID	100	14	0.983663
M8160334.52#	PESU	MID	100	12	0.980925
N6290238.20#	PESU	MID	100	23	0.946942
N7012145.28#	PESU	MID	96.87	32	0.931696
M8230147.06#	PESU	MID	100	12	0.978859
N7240556.06#	PESU	MID	94.11	34	0.850622
N8062323.17#	PESU	MID	100	12	0.981061
N8200148.00#	PESU	MID	100	19	0.882752
N8301956.56#	PESU	MID	100	20	0.987539
N8120243.04#	PESU	MID	100	14	0.913479
M8140123.43#	PESU	MID	100	16	0.862002
M7300257.47#	PESU	MID	100	17	0.98598
N7140115.59#	PESU	MID	95.45	22	0.857599
M9180358.18#	MYSO	MYOTIS	100	13	0.860004
N7240555.34#	PESU	MID	94.11	17	0.868587
N8260231.55#	PESU	MID	100	18	0.987172
N6292312.13#	PESU	MID	97.05	34	0.935573
M7070344.16#	PESU	MID	95.45	22	0.9007
N6290403.28#	PESU	MID	100	13	0.982586
M8180020.44#	PESU	MID	100	16	0.862592
N8222018.55#	PESU	MID	94.73	19	0.886479
N8140323.08#	PESU	MID	100	12	0.948311
N8062040.33#	PESU	MID	100	26	0.948743
M6240356.50#	PESU	MID	100	19	0.987879
M7280142.44#	PESU	MID	94.73	19	0.886145
N8010143.51#	PESU	MID	100	12	0.898621
M7310251.44#	PESU	MID	100	16	0.924148
N8302005.58#	PESU	MID	100	20	0.98211
M8042331.57#	PESU	MID	100	11	0.977907
N7242044.10#	PESU	MID	95.83	24	0.897242
N6252101.32#	PESU	MID	100	16	0.984701

N6012107.34#	PESU	MID	100	19	0.935534
N9090102.09#	PESU	MID	100	13	0.897279
N8142256.01#	PESU	MID	93.33	15	0.85484
M7250230.04#	PESU	MID	100	16	0.984186
M7232340.19#	PESU	MID	97.14	35	0.928899
N7210542.32#	PESU	MID	100	11	0.965244
N8120550.10#	PESU	MID	100	23	0.988984
N6180241.16#	PESU	MID	100	20	0.986769
M8100051.29#	PESU	MID	100	21	0.941753
M7050209.04#	PESU	MID	100	17	0.985569
M9302347.40#	PESU	MID	100	14	0.911935
M9302347.40#	PESU	MID	100	14	0.911935
N9050305.04#	PESU	MID	100	11	0.979674
M8190124.19#	PESU	MID	94.11	17	0.870853
M8290054.32#	PESU	MID	100	13	0.981582
N7312132.49#	PESU	MID	100	13	0.982452
N8130617.28#	PESU	MID	100	13	0.905073
M8150243.35#	PESU	MID	100	16	0.923478
M6290044.20#	PESU	MID	100	17	0.980788
M7270538.06#	PESU	MID	100	13	0.974742
N8142330.54#	PESU	MID	100	12	0.980976
N8212008.57#	PESU	MID	97.29	37	0.911677
M8150329.43#	PESU	MID	100	15	0.98364
M8212247.47#	PESU	MID	100	11	0.979239
M7040342.15#	PESU	MID	100	15	0.918044
M8150145.26#	PESU	MID	100	13	0.982793
N8100107.06#	PESU	MID	100	18	0.980396
M7252218.50#	PESU	MID	100	25	0.990657
N7090406.54#	PESU	MID	100	18	0.983638
N8060225.25#	PESU	MID	100	15	0.978874
M7220215.56#	PESU	MID	100	13	0.903574
M8220141.49#	PESU	MID	100	15	0.981223
N8202316.59#	PESU	MID	100	15	0.91899
N8102154.44#	PESU	MID	100	18	0.909844
N6052115.14#	PESU	MID	100	11	0.889002
N9120320.13#	LACI	LOW	100	11	0.979817
M7250238.14#	PESU	MID	95.65	23	0.863249
N8130041.48#	PESU	MID	100	12	0.981384
N8270415.54#	PESU	MID	94.11	17	0.873438
N7230213.35#	PESU	MID	100	11	0.976465
N6180121.26#	PESU	MID	96.55	29	0.922691
M8110302.25#	PESU	MID	95.83	24	0.867515
N8102119.55#	PESU	MID	100	14	0.98203

M8252338.18#	LACI	LOW	100	16	0.913122
MA150251.49#	LANO	LOW	100	13	0.975155
MA250302.43#	LANO	LOW	100	13	0.981254
M8100034.26#	NYHU	MID	100	13	0.860306
M9012141.53#	LANO	LOW	100	28	0.88377
M7100511.28#	MYLU	MYOTIS	91.66	12	0.874841
M7112239.00#	EPFU	LOW	100	21	0.928612
NA230322.00#	LANO	LOW	100	17	0.91547
N7260120.39#	LACI	LOW	100	16	0.985582
N8150039.07#	LACI	LOW	100	16	0.957202
N8130045.02#	LANO	LOW	100	18	0.941765
N9120320.13#	LACI	LOW	100	11	0.979817
N8250003.24#	LACI	LOW	100	11	0.979781
N8140419.59#	LACI	LOW	100	14	0.98393
N7082200.04#	LANO	LOW	100	11	0.908845
N7170455.10#	LACI	LOW	100	11	0.978667
N9220346.46#	LANO	LOW	100	12	0.978762
N9242019.18#	LANO	LOW	100	14	0.87375
N9292032.25#	LACI	LOW	100	16	0.924412
NA130128.03#	LACI	LOW	100	14	0.984051
NA140016.09#	LANO	LOW	100	12	0.866067
N5290414.30#	LANO	LOW	100	15	0.885416
N6062236.19#	LANO	LOW	100	18	0.929926
N6070136.48#	LANO	LOW	100	17	0.906613

Appendix 2: Biological data from captures during the 2013 season. All captures from 19:00 until 00:15 were captured using mist nets. Captures that happened during daytime hours were roosting on a landowner's house. These four bats were pulled from the roosting location and biological data was retrieved. Data from 2012 was stolen, therefore is not included in this table. MFC= Muddy Fork Creek, Prairie Grove, Burd= Burdette location, M= Male, F= Female, A= Adult, J= Juvenile, NR= Non-reproductive, EST= Estrus, Lac= Lactating, Preg= Pregnant, Post= Post-lactating, Scrot= Scrotal. PESU= Perimyotis subflavus (Tricolored bat), MYGR= Myotis grisescens (Gray bat), EPFU= Eptesicus fuscus (Big-brown bat), LABO= Lasiurus borealis (Eastern-red bat), MYLE= Myotis leibii (Small-footed bat), NYHU= Nycticeius humeralis (Evening bat), LACI= Lasiurus cinereus (Hoary bat), MYSE= Myotis septentrionalis (Northern long-eared bat).

Date	Location	Time	Species	Sex (M/F)	Age (A/J)	Repro. Status	FAL (mm)	Mass (g)
11-Jun-13	MFC	21:15	PESU	M	A	NR	34.4	6
11-Jun-13	MFC	22:20	MYGR	F	A	LAC	44.9	12
11-Jun-13	MFC	22:20	MYGR			Escaped from net		
11-Jun-13	MFC	22:20	EPFU	M	A	NR	50.1	17
11-Jun-13	MFC	23:00	MYGR	M	A	NR	43.52	11
11-Jun-13	MFC	23:00	PESU	M	A	NR	35.06	6
11-Jun-13	MFC	23:00	PESU	F	A	PREG	33.38	8
11-Jun-13	MFC	23:15	MYGR	M	A	NR	43.56	10
11-Jun-13	MFC	0:15	LABO	M	A	NR	33.16	11
17-Jul-13	Ponca	20:50	LABO	F	A	POST	40.59	9.5
17-Jul-13	Ponca	20:50	LABO	F	A	LAC	43.52	11
17-Jul-13	Ponca	20:50	LABO	F	A	POST	41.62	11.5
17-Jul-13	Ponca	20:50	LABO	F	A	POST		
17-Jul-13	Ponca	21:15	LABO			Escaped from net		
17-Jul-13	Ponca	21:15	LABO	F	J	NR	41.02	9.5
17-Jul-13	Ponca	21:30	LABO	F	J	NR	41.72	10
17-Jul-13	Ponca	21:30	LABO	M	A	NR	40.14	11
17-Jul-13	Ponca	21:30	LABO	F	A	POST	42.04	11.5
17-Jul-13	Ponca	21:45	LABO	M	J	NR	40.58	9
17-Jul-13	Ponca	21:45	LABO	F	A	PREG	42.78	17
17-Jul-13	Ponca	22:15	LABO	F	J	NR	41.04	9.5
17-Jul-13	Ponca	22:15	LABO	M	A	NR	40.57	11
17-Jul-13	Ponca	22:15	LABO			Released at net		
17-Jul-13	Ponca	22:15	LABO			Released at net		
19-Jul-13	Ponca	13:10	MYLE	M	A	NR	30.68	5
19-Jul-13	Ponca	21:10	LABO	F	A	PREG	41.72	14
19-Jul-13	Ponca	21:10	PESU	M	A	NR	34.4	5

19-Jul-13	Ponca	22:00	LABO	F	A	PREG	40.62	15
19-Jul-13	Ponca	22:00	LABO	F	A	PREG	41.92	13
19-Jul-13	Ponca	22:00	NYHU	M	A	NR	36.24	9
19-Jul-13	Ponca	22:00	PESU	M	A	NR	35.82	5.5
19-Jul-13	Ponca	22:30	LABO	F	A	PREG	44.75	17
21-Jul-13	MFC	21:30	MYGR	M	A	NR	44.42	12
21-Jul-13	MFC	21:30	LABO	M	J	NR	34.34	9
21-Jul-13	MFC	21:30	LABO	F	A	LAC	41.58	13
21-Jul-13	MFC	21:30	LABO	F	J	NR	41.94	11
21-Jul-13	MFC	21:30	LABO	F	A	PREG	44.6	17
21-Jul-13	MFC	22:15	MYGR	F	J	NR	43.9	10
21-Jul-13	MFC	22:15	PESU	F	A	PREG	35.58	7
21-Jul-13	MFC	22:15	LABO	M	J	NR	41.1	10
21-Jul-13	MFC	22:15	LABO	F	J	NR	39.92	10
21-Jul-13	MFC	22:15	PESU	F	A	PREG	33.4	8
21-Jul-13	MFC	22:15	MYGR	F	A	LAC	44.22	11
25-Jul-13	Burd	21:45	LABO	M	A	NR	42.35	12
16-Aug-13	MFC	21:25	LABO	F	A	POST	41.56	13.5
16-Aug-13	MFC	21:25	LABO	M	A	NR	43.22	13
16-Aug-13	MFC	21:25	MYGR	F	A	EST	46.4	10
16-Aug-13	MFC	21:25	MYGR	M	A	NR	46.3	9
16-Aug-13	MFC	21:25	LABO	M	A	NR	40.1	11
16-Aug-13	MFC	21:25	LABO	M	A	SCROT	41.04	13
16-Aug-13	MFC	21:55	MYGR	F	A	EST	43.5	11
16-Aug-13	MFC	21:55	MYGR	F	A	EST	44.9	11
16-Aug-13	MFC	21:55	LABO	M	A	NR	41.32	13
16-Aug-13	MFC	21:55	MYGR	M	A	NR	43.22	9.5
16-Aug-13	MFC	21:55	MYGR	M	A	NR	42.9	9.5
16-Aug-13	MFC	21:55	LACI	M	A	NR	53.4	26.5
16-Aug-13	MFC	22:30	EPFU	F	A	PREG	50.94	20
16-Aug-13	MFC	22:30	PESU	M	A	NR	32.69	6
16-Aug-13	MFC	23:05	MYGR	M	A	NR	45.94	12.5
16-Aug-13	MFC	23:05	MYGR		ESCAPED FROM NET			
16-Aug-13	MFC	23:05	LABO	M	A	SCROT	40.26	11
17-Aug-13	Ponca	14:16	MYSE	M	A	NR	36.26	6
17-Aug-13	Ponca	14:38	MYSE	F	A	POST	37.46	5
7-Sep-13	Ponca	12:18	EPFU	F	A	NR	51.28	25
7-Sep-13	MFC	20:15	PESU	M	A	NR	33.54	7
7-Sep-13	MFC	20:45	MYGR	M	A	NR	43.72	10
7-Sep-13	MFC	21:10	MYGR	M	A	SCROT	45.42	10.5
7-Sep-13	MFC	21:10	MYGR	M	A	SCROT	45.42	11
7-Sep-13	MFC	21:10	MYGR	F	A	NR	43.75	11
7-Sep-13	MFC	22:00	LABO	M	A	SCROT	33.02	9

19-Oct-13	MFC	19:15	MYGR	M	A	SCROT	43.8	11
19-Oct-13	MFC	19:15	LABO	M	A	NR	38.6	9