Assessing Bat and Bird Fatality Risk at Wind Farm Sites using Acoustic Detectors

A DISSERTATION
SUBMITTED TO THE FACULTY OF THE
UNIVERSITY OF MINNESOTA
BY

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

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August 2014

Acknowledgments

Abstract

Wind power is a promising clean energy technology that has grown rapidly in recent years (EIA 2013). In spite of its environmentally friendly reputation, industrial wind energy generation can have serious impacts on wildlife. Bat and bird collision fatality rates have been alarmingly high at some wind farms. Proper siting of wind facilities may help minimize collision impacts as the wind energy industry continues to grow. Bat and bird fatality rates vary greatly among sites; however, there is no reliable method for assessing collision risk prior to development. My goal was to develop a method for predicting fatality rates based on nocturnal activity patterns measured by ground-level recording of bat and bird calls. For three years, I monitored bat and bird activity using ultrasonic-acoustic detectors at 160 locations, including eight wind farms and a variety of landscape settings to: 1) examine the capabilities of the detector for use in pre-construction site assessment, 2) evaluate the ability of an automated bat call identification program to identify the species of recorded bat calls, 3) determine how pass rates relate to fatality rates for use in predictive models based on pre-construction recordings, 4) examine variation in pass rates with respect to pre-specified landscape and habitat features, 5) examine how activity patterns might differ before versus after a wind facility is built, and 6) investigate whether bat activity levels are elevated near turbines. Ground-based recording was found to be a useful method for studying near-ground bat activity patterns at multiple scales, but patterns of acoustic activity of birds were less clear and apparent only at the most coarse geographic scale. The automated bat call identification program produced mixed results among species and geographic regions. No relations between bat pass rates and estimated fatality rates among wind farms were found, either for all bats or for migratory tree-roosting species. Large differences in bat and bird activity among geographic regions were found, with highest activity levels near Great Lakes coastlines. Also, bat and bird activity levels near the edge of forested river corridors in agricultural settings in Minnesota were found to be higher than those farther from the edge. Evaluation of a variety of predictive models of pass rates revealed distance to water, distance to trees, and ecoregion as good predictors of bat activity levels. Although some differences in bird activity were evident at the broadest geographic scale, models were of limited usefulness in explaining spatial variation in bird activity. Acoustic activity measured by ground-based recorders was not a good predictor of bat fatalities at wind farms; however, it did reveal local and regional patterns that may be useful for siting wind energy facilities in low-impact areas.

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Definitions

Array or **Distance Array** – series of 3, 4, or 5 recording sites arranged in a linear transect, with recorders placed at specified distances from a particular object (e.g., a wind turbine or a forest edge).

Location – general area (wind farm, array, etc.) containing a group of recording sites. This is different from a "site," which is a place where a single recorder was placed. An example of a location would be the Top of Iowa wind farm, where four recorders were placed throughout the facility.

Location Mean – mean of all nightly pass counts at all sites within a location.

Pass – one audio file containing one or more bat or bird calls. Recorders begin creating a file when bat or bird vocalizations are initially detected, and close the file after one second (for bats) or two seconds (for birds) has passed without any sounds. This "triggering" mechanism theoretically captures the sequence of vocalizations of one or more bats or birds as they fly past a microphone. Pass counts are used as an index of bat and bird activity. More detail is given in the General Methods section.

Pass count or **nightly pass count** – number of passes recorded at one recording site on one night

Pass rate – mean pass count over a period of time, generally for a single site. In most cases, this is equivalent to Site Mean.

Recorder-night – one night (civil sunset to civil sunrise) in which a recorder was operating (collecting data, regardless of pass count) for at least four hours. Nights with less than four hours of recording time were excluded from analyses.

Site or **recording site** – place where a single recording unit was set up. This is different from a "location," which consists of a group of sites within in a larger area. For example, the Top of Iowa location comprised four sites named Top1, Top2, Top3, and Top4.

Site mean or **pass rate** – mean of all pass counts at a single recording site, incorporating all years and seasons that a recorder was deployed at the site. Each recording site has one site mean.

Site-year mean – mean of pass counts collected during a specified year. Most sites have two or three site-year means.

Abbreviations of bat species

The following abbreviations are used throughout this document. Focal species were species with sufficient numbers of passes in the training data to allow for full analyses of pass rates at the species level (see General Results, Species Identification for more detail). Passes of these species were used to evaluate the automated species identification software, as well as to address research questions about how bat activity related to fatalities, landscape features, and wind farms.

Abbreviation	Common Name	Scientific Name	Focal Species?
EPFU	big brown bat	*Eptesicus fuscus*	Yes
LABO	eastern red bat	*Lasiurus borealis*	Yes
LACI	hoary bat	*Lasiurus cinereus*	Yes
LANO	silver-haired bat	*Lasionycteris noctivagans*	Yes
MYLU	little brown bat	*Myotis lucifugus*	Yes
MYSE	northern myotis	*Myotis septentrionalis*	Yes
NYHU	evening bat	*Nycticeius humeralis*	Yes
PESU	tricolored bat	*Perimyotis subflavus*	Yes
TABR	Mexican free-tailed bat	*Tadarida brasiliensis*	No

GENERAL INTRODUCTION

Wind energy is a relatively clean renewable energy resource that has expanded rapidly to become a large-scale contributor to domestic electricity production. Development is expected to continue growing rapidly given the abundant wind resources of the United States. As with every electrical generation source (Fthenakis and Kim 2009, Gagnon et al. 2002), wind energy has impacts on the environment. One particularly visible impact is direct fatalities of bats and birds, sometimes at alarmingly high rates, caused by collisions with turbines or barotrauma associated with blade rotation (Baerwald et al. 2008). There are other potential impacts to wildlife from wind energy development, such as avoidance of turbines (e.g., Pruett et al. 2009, Shaffer and Johnson 2008), but I focused on fatality rates and the potential to use acoustic detectors to monitor bat and bird activity prior to development as a means of selecting wind energy sites that would have minimal fatality impacts.

Wind-wildlife research is a relatively new area of study, beginning in the late 1980s when researchers began finding dead raptors underneath some of the first industrial wind energy generators constructed in the United States at Altamont Pass in California (Howell and Didonato 1991, Orloff and Flannery 1992). However, the study of deaths of flying animals at man-made towers is not a recent phenomenon and findings of previous studies of tower kill events can provide us with some starting points from which to address wind turbine fatalities. Studies of tower kills and the mechanisms behind them offer a much longer historical perspective and a much broader set of data within which to view collision events.

Tower Kills

Tower kills are events in which birds or bats collide with tall buildings or utility structures such as television towers or power plant smokestacks. Some of the earliest tower kill observations were en-masse collisions of migrating birds with lighthouses. These events were familiar to lighthouse keepers, whom Allen (1880) queried via written survey in an effort to formalize and compile their casual observations in one of the earliest tower kill studies. This report was followed shortly thereafter by Barrington's (1900) documentation of over 1000 surveys from 42 lighthouses and light-ships on and off the coasts of Ireland. Several important characteristics of

tower kills that would recur in studies for the next century were initially observed in these early reports. First, a seasonal pattern of larger and more frequent kills in autumn was clear. Second, most lighthouses experienced heavier kills during fog, inclement weather, or the passage of cold fronts. Third, the attraction of birds, but not bats, to light, especially static light (not rotating or blinking) was evident among the many compiled reports. One keeper at a static light in Louisiana reported that large numbers of birds "flutter against the glass like moths." Fourth, Allen (1880) noted that there was some evidence of a coarse geographical pattern among kills at lighthouses along the eastern coast of the United States. Lighthouses north of Cape May in southern New Jersey (n = 17) experienced very low fatality rates (maximum kills of 20 or fewer per night) while the Cape May lighthouse and all lighthouses south of it on the Atlantic and Gulf coasts (n = 5) had high fatality rates, including events with hundreds of kills. Although the sample size is small, this difference may be a result of the accumulation of migrants closer to wintering locations in the southeast, or an example of the barrier effect (Alerstam 2001, Seeland et al. 2012), with increasing aggregation of migrants along coastlines as southerly and south-easterly flying birds encounter the Atlantic Ocean.

Another early-emerging pattern was the almost complete absence of bats. Among Barrington's (1900) 30,000 bird observations, reports of bats were rare, and only 3 specimens were documented, one of which was found dead, the other two being caught alive. From the perspective of wind energy impact assessment, the lack of bats in these early data begins to suggest a fundamental difference between the mechanisms behind bat and bird collisions. The few bats that were found also indicate that in at least some instances, bats fly considerable distances over large bodies of water. The dead bat described by Barrington was found on a lightvessel about 14 km off the coast in the Irish Sea in late September. One of the live bats from those reports was also caught about 8 km offshore, in mid-April. These accounts of bats being caught offshore during migration seasons are not unique, for example Norton (1930) reported a male eastern red bat (*Lasiurus borealis*) being picked off the sail of a swordfishing boat more than 160 km offshore, east of Cape Cod in the northern Atlantic in late August.

In addition to lighthouses, early reports in newspapers and regional ornithological publications documented mass fatalities of birds at a wide variety of structures. These included buildings such as the Washington Monument (Overing 1936, 1938), Milwaukee Exposition Building (Kumlien 1888), and Empire State Building (Terres 1956); street lamps (Gastman 1886); and later at power station smokestacks and cooling towers (Weir 1973, Rybak 1973). Several patterns from early

lighthouse reports are reinforced by these studies: larger and more frequent kills occur during autumn migration, and higher numbers of fatalities occur at structures with bright lights. Overing (1936) stated that while the Washington Monument was illuminated by floodlights prior to midnight, he and assistants would actively collect birds as they came "tumbling down its sides", until the lights went off, at which point the collisions largely ceased. Both Rybak (1973) and Weir (1973) noticed dramatic reductions in kills after floodlights were removed or turned off.

An increase in the number of published reports on tower kills (e.g., see Avery 1978) may indicate that attention to the issue increased dramatically in the second half of the 20th century as focus shifted to television and communication towers. Large fatality events in the northeastern, southeastern, and midwestern United States seemed to start occurring with some regularity upon the installation of these structures in the 1950's and were reported in local or national journals by citizens and scientists alike. Kemper (1959, 1964), Laskey (1969), Taylor and Anderson (1973), Seets and Bohlen (1977), and Welles (1978) all documented one or more fatality event involving over 1,000 birds each. The large numbers of fatalities had researchers collecting dead birds using rakes and counting carcasses by the bushel. One infamous and widespread spate of tower kills occurred in October 1954, resulting in fatalities across the entire eastern U.S. from New York to Georgia and as far west as Kansas. The event coincided with the passage of a large cold front moving southward across the eastern U.S. from October 5-7. Johnston and Haines (1957) reviewed reports from 26 locations regarding tower kills that occurred during that event, which resulted in over 100,000 documented fatalities.

Despite the intensity of collision events, most early observers reported the events in a tone of intrigue rather than concern, and casualties were often viewed as samples of aerial migrants that could be used to study migration patterns. In some ways, the diversity of bird carcasses provided a wider (and perhaps more randomly selected) set of observations than traditional studies, especially for secretive species. For example, the first black rail in central North Carolina was found under a TV tower near Raleigh (Browne and Post 1972), and Kemper (1996) commented on the irony of spotting only a single yellow rail in many years as a recreational birder, and then collecting 12 under a TV tower in Eau Claire, Wisconsin.

Tower kill data are plentiful, and can provide valuable information for the study of bird migration. Carcasses from tower kills can be thought of as samples of migrants at a particular place and time; however, there are questions regarding the randomness of these samples. These

questions relate to both the selection of particular tower sites as study sites, and the selection (by collision) of particular birds from the group of all migrants flying through the area. It is evident that many casual reports of kill events to local publications are submitted only when large kills take place. Additionally, towers selected for formal studies are often chosen as a result of initial incidental findings, or when the tower is otherwise known beforehand to cause fatalities. Studies seldom quantify search effort, making it difficult to estimate total mortality or even compare events.

To address the question of whether tower kills are representative of nocturnal migrants, Tordoff and Mengel (1954) conducted a thorough analysis of data gathered at a TV tower near Topeka, KS. They posited that if migrants are distributed uniformly longitudinally (i.e., broad front), then large-scale quantification of migratory movements from tower kill data might be possible. However, after examining the distributions of various measurements taken from each specimen, they arrived at the conclusion that the carcasses found after a tower kill are likely not a random selection of migrants across species, but may be a random selection across other variables within species, such as age, sex, body condition, and molt. As such they might be useful for studying the distributions of those characteristics among migrants flying in the vicinity of the Topeka tower during fatality events. For species in which migration timing varies by age or breeding status, these samples would not be representative of the entire population, but would provide a snapshot of the group of birds engaged in migration at the time of each event.

From early reports, we know that season (autumn), weather conditions (passage of cold fronts), and steady lighting are likely factors in determining when tower kills take place and how many birds are killed. More recently, these historic data sets have been used to examine how particular characteristics of communication towers affect fatality rates, and have confirmed that both tower height and the number of guy wires are additional contributing factors (Longcore 2008).

Fatality events seem to involve particular species more commonly than others. Neotropical migrant passerines, and in particular warblers and vireos, often show up in fatality counts in the highest numbers, and are mentioned more frequently than other groups of species in reports. This is apparent throughout historical data (Avery 1978) as well as in more recent analyses (e.g., Shire 2000). From the few records available, there does seem to be a species pattern among bat fatalities at towers as well. Eastern red bats (*Lasiurus borealis*) are by far the most common. Among tower kill reports from 1880-1980, a total of 39 bats had the following composition: 32

eastern red bats, 2 hoary bats (*L. cinereus*), 2 big brown (*Eptesicus fuscus*), 2 little brown (*Myotis lucifugus*), and 1 silver-haired bat (*Lasionycteris noctivagans*; Saunders 1930, Overing 1936, Carlson 1955, Laskey 1956, Terres 1956, Van Gelder 1956, Kemper 1959, Ganier 1962, Gollop 1965, Rosche, 1969, Avery 1972, Rybak, 1973, Weir 1973).

From the perspective of wind-wildlife research, the surprising finding from tower kill reports is the nearly complete absence of bats among the thousands of dead birds. The mechanisms that cause bird fatalities at towers may be the same ones that result in bird collisions at wind farms, but it is clear that bat fatalities are an entirely different phenomenon.

Fatalities at Wind Farms

The Altamont Pass raptor fatalities found by Orloff and Flannery (1992) and later studied by Smallwood and Thelander (2005) raised a new wave of concern about bird mortality associated with a different tower-based technology that had the potential for much more widespread use throughout the country. Bat fatalities had been documented at wind turbines in Australia (Hall and Richards 1972) and sporadically at early wind developments in the United States (e.g., Anderson et al. 2000), but wind impacts were considered primarily an issue with birds, in particular raptors, until large-scale bat mortality was found at two Appalachian ridge-top wind farms in West Virginia (Kerns and Kerlinger 2004) and Tennessee (Fiedler 2004). These sites had estimated fatality rates on the order of 50 to 60 (Fiedler 2007) bats per turbine per year, respectively, and brought bats to the forefront of wind-wildlife research.

Whereas the first reports of high fatality rates came from a very specific type of wind facility on forested ridges in Appalachia, alarming rates have since been discovered in other regions and settings from Midwestern farmland (Grodsky et al. 2011) to Rocky Mountain foothills (Baerwald and Barclay 2009). The Midwest has recently been identified as a region with particularly high bat fatality rates (Arnett and Baerwald 2013).

Studies have consistently shown that bat fatalities at wind farms in North America frequently involve migratory tree-roosting bats, and generally occur in late summer and early autumn (Johnson 2005, Kunz et al. 2007b, Arnett et al. 2008). Avian impacts have been more variable, but studies at modern facilities have found that nocturnal migrants usually comprise a large portion of fatalities (Erickson et al. 2002) and that the largest fatality events occur during spring

and autumn migration periods (Johnson et al. 2000, Young et al 2003, Kerns and Kerlinger 2004). It has also been observed that during spring and autumn migration, the species composition and abundance observed during daytime bird surveys have not been reflected in the composition of bird carcasses found during fatality searches (Johnson et al. 2000, Johnson and Erickson 2010), which could be further evidence that nocturnally active birds are at greatest risk.

These findings indicate that the ability to predict fatality risks to bats and birds at a prospective site may rely on measuring nocturnal activity during migration. Bats and birds flying under the maximum turbine height are assumed to be at the highest risk, so measuring activity within this relatively low zone (150m above ground level) was considered particularly important. Surveying this activity at wind farms where fatalities rates are known may allow us to relate acoustic observations to fatalities and develop a predictive model of fatality rate based on pass rate.

Landscape features may influence low-altitude migratory density or daily movement patterns during migration if they provide visual cues or food resources for migrant birds (Buler et al. 2007), or roost sites for migrant bats (Baerwald and Barclay 2009). Measuring acoustic activity at various distances from particular features may provide additional information that can be used to predict fatality risks at prospective sites. Acoustic detection has been a popular method for both pre-construction and post-construction monitoring of bat activity (e.g., Kunz et al. 2007a, USFWS 2012) but the relationship between acoustic activity and fatalities has not been well established. Recent attempts to do so have had some limited success (Arnett et al. 2006, Hein et al. 2013).

Objectives

My goal was to evaluate the use of ultrasonic/acoustic recording as a tool for wind farm site selection by examining the relationships between acoustic detection rates and wind farm fatalities, prominent landscape features, and wind farms themselves. Specifically, my objectives were to:

(1)   Evaluate the ability of an ultrasonic/acoustic recorder, deployed at ground-level, to measure activity levels of bats and birds by recording nocturnal calls at current and potential wind power sites

(2)   Assess the performance of an automated bat call identification program at detecting bat calls within sound files and accurately identifying the species of the calls

(3)   Relate acoustic activity of bats to fatality rate estimates at operating wind farms

(4)   Evaluate whether bat or bird activity varies in relation to particular landscape features

(5)   Measure changes in bat and bird activity before vs. after a wind farm is constructed

(6)   Examine whether bird or bat activity varies with distance from turbines

Objectives 1 and 2 are addressed in the General sections at the beginning and end of this document. Objective 1 is also addressed in association with the other objectives in each chapter. Objective 3 is addressed in Chapter 1, objective 4 is addressed in Chapter 2, and objectives 5 and 6 are addressed in Chapter 3.

GENERAL METHODS

I recorded bat and bird vocalizations using a two-microphone stereo recorder, which allowed the simultaneous capture of bat and bird calls. I placed recorders in strategic locations chosen to address specific research objectives. The recorders ran nightly from civil sunset to civil sunrise, during field seasons, March 15 – June 1, and August 1 – November 15, unless otherwise noted for a particular study site. I collected data from the spring of 2010 to the autumn of 2012. I began with 19 study sites and added 141 sites (total 160 sites) over the course of the project, which included expansions associated with several collaborations, especially a large expansion in the Great Lakes region working with the U.S. Fish and Wildlife Service (USFWS). Data from field sites were processed in two phases: phase 1 was to identify all bird or bat passes in the recordings, producing a pass count for each night at each recording site, and phase 2 was to determine the species of each bat pass found in phase 1. Most analyses were performed with pass counts or mean pass counts (e.g., site means). Estimated pass counts were used in the case of species-specific analyses, which relied on an automated identification process. Pass counts were considered to be an index of bat or bird activity within the recording range of the microphone.

Recording Equipment

After experimenting with several homemade recording setups similar to those used by Dawson (2007) and Evans (2005), as well as assessing the capabilities of several mass-produced devices made specifically for detecting bird or bat calls, I chose the Wildlife Acoustics SM2Bat+ (SM2) recorder for a variety of reasons. The SM2 is an autonomous, programmable recording device that allows for simultaneous recording by two microphones, and has the ability to capture sounds over a wide frequency range, which includes the ultrasonic range used by bats. The recorder is powered either by internal D cell batteries, or by an external battery for longer field deployment. Data are recorded to interchangeable SD data cards. The electronic components are housed in a hard plastic box with a weatherproof cover. Components such as microphones and power cables are attached via waterproof ports on the exterior of the recorder. These features made the SM2 the best option for monitoring bat and bird call activity at many remote field locations over long recording intervals, consistent with my study design.

Birds were recorded on the right channel using a microphone designed to capture sounds in the acoustic range (< 16 kHz). The recorder was programmed to filter out sounds below 2 kHz as well as sounds above 16 kHz. The purpose of these filtering settings was to capture sounds within the acoustic range of most bird calls, while excluding much of the background noise from weather, farming equipment, and roads that is often below 2 kHz. Filtering out upper frequency sounds excluded higher-frequency insect noise above 16 kHz. Bats were recorded on the left channel using an ultrasonic microphone designed to capture bat calls. Sounds below 16 kHz were filtered out on the left channel to exclude lower-frequency noise while recording bat calls in the upper frequency range (16 to 192 kHz).

During the 2012 season, "night flight call" (NFC) bird microphones were used at recording sites in the Great Lakes region, in order to improve the reception of high-elevation chip notes of nocturnal migrants. The microphone element is attached to the middle of a square plastic surface, reminiscent of the homemade night flight call microphone design provided by Evans (2005), which uses a plastic dinner plate for a similar purpose. The NFC microphones were mounted atop a telescoping flag pole, which raised the microphone approximately 5 m above the ground. The purpose of the plastic surface is to increase the detection of sounds within the nocturnal chip note range (about 2-5 kHz), and also block ground noise from beneath the microphone. Elevating the microphone was intended to allow the plate to block noises from a wider area under the plate. In this configuration, the bat microphone remained attached to the recorder, near ground level.

Figure 1: Pictures of deployed recorder (left) and recorder with elevated NFC bird microphone (right)

The SM2 records 16-bit samples at a frequency of 192 kHz, which allows it to capture sounds between 0 and 96 kHz, according to the Nyquist–Shannon sampling theorem (Shannon 1949). All bats in the Upper Midwest vocalize within this range, so this sampling frequency was adequate for the purposes of this project. This recording capability results in very data-dense sound files, and necessitates large-capacity data cards. Each recorder was equipped with two high-capacity secure digital (SD) data cards of 32 GB each, providing a total of 64 GB of data capacity for each 5- to 10-night recording interval.

Filtering out low-frequency sounds eliminated much of the extraneous noise picked up by the acoustic and ultrasonic microphones, but it did not eliminate all noise, which could obscure bat and bird calls and also flood data files with unwanted sounds. Wind was the most common noise interfering with microphone reception (many sites were located at active or potential wind energy sites), but sounds from insects, rustling vegetation, rain, and farming equipment (e.g., grain dryers, combines) also created unwanted sound files or interfered with recordings of calls, making them more difficult to identify.

To address this problem, I built PVC "ears" to surround each microphone and block them from ground-based noises while allowing reception of sounds from overhead (see Figure 1, left). Each ear was constructed from a PVC cap (bowl-shape) and a coupling (hollow cylinder shape). The coupling was attached to the cap using Gorilla Tape to form a large cup, about 12cm in diameter

and 20cm deep. A hole was drilled into the side about 3cm from the bottom of the cup for the microphone and a small hole was drilled into the bottom of the cup for drainage. A strip of rubber-based carpeting (bathmat material) was glued around the top rim of the cup to prevent wind shear across the opening, and a small patch of carpeting was glued to the bottom, next to the drainage hole for the same purpose. Ears were attached to each side of the recorder by a wire around the top of the cup connected to the male end of a modified side-release plastic buckle (similar to a backpack buckle), with the female end adhered to the top of the recorder with a plastic-bonding glue. The buckle made it easy to remove the ear from the recorder, allowing quick access to the microphone.

Even with the ears, microphones still picked up weather and ground-based noise, particularly on the acoustic side. For the 2012 season, I added sound-absorbent foam (typically used in construction of sound-deadening walls) to the inside of the acoustic microphone's ear, to enhance the sound insulation of the wall and prevent sounds from reverberating inside the ear.

Ears were used for two reasons: to improve the detection of calls, and to standardize the microphone micro-environment among recording locations. Call detection is improved by eliminating extraneous noise, since call recognition (both manual and automatic) is heavily dependent on signal-to-noise ratio in addition to call loudness and microphone sensitivity. However, achieving the objectives of this project required, in large part, making accurate comparisons between and among recorders and groups of recorders. For this reason, reducing variation among sites in the recorders' ability to detect calls was of the highest importance. Noise sources such as wind and insects vary greatly by site, and enclosing the microphones reduced the effects of site-specific conditions on the ability to record bat and bird calls.

Microphone reception depends on both atmospheric conditions (wind, noise) and characteristics of the call itself (distance of bird/bat from the microphone and loudness of the sound at the source). Acoustic microphones were tested using recorded calls of several species played at various distances, up to 250m away from the recorder. That distance is 100m higher than the top of the rotor-swept zone of the most modern turbines used at industrial wind farms. Tests were carried out both at an open field in a state park on a calm day, and at a wind farm in an agricultural setting on a windy day, while surrounding turbines were turning (producing the typical "whoosh" sound). At the wind farm, the recorder was positioned 50m from the base of an operating turbine. All bird sounds at each distance were recorded and were visible in the

spectrograms, allowing for visual identification. I also recorded a "whistling" turbine, which has a damaged or misshaped blade and produces a whistling sound that shows up as a clean wave-like pattern in a spectrogram, and found that a whistling turbine would not substantially inhibit the recording or identification of bird passes.

Bat microphone reception range was not well known, but is limited due to the quick attenuation of high frequency sounds in air. I tested bat microphones at the beginning of each season for simple operability by shaking keys (jingling keys produce ultrasonic noise that covers the entire frequency range of the recorders) 5 m away from the recorder, but they were not tested for range. Adams et al. (2012) found reception of SM2 microphone up to 25 m away using synthetic calls. One advantage of ultrasonic recording over recording in the acoustic frequency range is the lack of noise at higher frequencies. Aside from insects at a few sites, most ultrasonic recordings were relatively clean, in contrast to bird recordings which could be masked by a variety of extraneous noises.

Configuration

Recorders were programmed at the beginning of each season using a .set file generated by the Song Meter Configuration Utility loaded onto an SD card. Recorders were programmed to operate from civil sunset to civil sunrise each night. The sampling rate was 192,000 stereo with 0 gain on both sides. WAC4 compression was used to reduce data size and increase the number of recordings that could be written to an SD card. Sound filters are described above, but used the following parameters: left high-pass filter fs/12 (16 kHz), left low-pass filter off, right high-pass filter fs/96 (2 kHz), right low-pass filter fs/12 (16 kHz), division ratio 16.

Triggering was used on both acoustic and ultrasonic channels. Triggering means that the recorder "listens" passively, but does not record to the data card when only silence is detected. When a sound of a certain loudness is detected, recording begins and continues until a specified amount of time (trigger window) without any sounds of the chosen loudness has elapsed. For each triggering event, a single WAV file is created. Some WAV files contain bat or bird vocalizations, and some do not (e.g., if an insect sound triggers the recording). One WAV file containing one or more bat or bird vocalization was considered one bat or bird "pass." WAV files containing only noise (e.g., insects, wind, rain) and no vocalizations were filtered out during phase 1 of data processing (see below). Recording bats over the course of multiple days requires triggering due to the extremely fast accumulation of data while recording at the high frequencies needed to

capture echolocation calls. At 192,000 samples per second (16 bit samples x 2 channels), active recording generates 2.8 GB per hour. I used triggering settings of 6 dB on both sides, with a 1-second window for bats and a 2-second window for birds, since bird calls are longer and have a slower cadence (longer gaps between calls) than bat calls.

Latitude and longitude were entered manually at the beginning of each season for each recorder, depending on its deployment location. The SM2 automatically calculates sunrise and sunset times based on its coordinate settings. Accurate time was verified for each recorder prior to each season, as well as during each battery and data card replacement in the field. The internal clock is powered by two AA batteries, which were tested at the beginning of each field season.

Deployment and Maintenance

A general location for each recorder was selected during the study design process. That location could be as nondescript as a large open area or the vicinity of a particular wind turbine, or as specific as a particular distance along a fence line or transect. Exact recorder locations were chosen when recorders were initially set up at study sites. Recorders were placed away from trees and water whenever possible. Many sites in agricultural settings were along fence lines, which were often the only locations that would not interfere with land use. Recorders were placed away from high-traffic roads to avoid excessive noise and vandalism, but within reasonable walking distance (less than 0.5 km) from low-traffic roads, to increase the number of recorders that could be accessed for battery and data card replacement in a day. A table with details of each recording site can be found in Appendix A.

Recorders were either attached to an existing structure (typically a fence post), or a new post was installed to support the recorder at the desired location. Recorders were attached to supporting structures using a metal wire loop connected with screws to the back of the recorder. Recorders were secured at each site such that they could not be easily removed by hand. Battery boxes were placed on the ground beneath the recorder.

During the 2010 season, internal D cell batteries were used to power the recorders. This configuration had a limited run time, and each recorder was accessed every 5 days to replace batteries and switch out data cards. In 2011, an external battery with much higher capacity (42 amp-hours) was used, extending the run time with recorders accessed every 14 days. I used 6-volt absorbent glass mat (AGM) batteries. AGM batteries are solid and non-spillable, which was

necessary for use in the field, especially where livestock were present. Batteries were housed in plastic tote boxes with lids secured by bungee cords, and placed on the ground beneath recorders. The bungee cord was also used to attach the tote to the fencepost or supporting structure that supported the recorder. In 2012, the external batteries were found to have reduced capacity because they had been over-discharged in the previous seasons and deployed in freezing temperatures during early spring and late autumn. I switched to a 10-day interval for the 2012 seasons to accommodate the reduced capacity.

Maintenance included replacing the drained internal batteries or external battery, collecting any full or partially full data cards and replacing them with empty cards, and checking that the time was correct. I performed maintenance on recorders in Minnesota, Iowa, and eastern Wisconsin (non-Great Lakes sites), and collaborators maintained other recorders (Table 1).

Table 1 Collaborators who collected data at remote sites

Collaborator	Site	Location	Recorders	Years
Texas Christian University	Wolf Ridge Wind Farm	NE Texas	4	2010, 2011, 2012
Bat Conservation International (BCI)	Casselman Wind Farm	SW Pennsylvania	8	2011
WEST Inc. and BCI	Penascal Wind Farm	South Texas	8	2011
BCI	Fowler Ridge Wind Farm	Indiana	12	2012
USFWS Region 3 Employees and Volunteers	Great Lakes Sites	WI, MI, OH, PA, NY	50	2010, 2011, 2012

Data Collection and Storage

Data cards were either collected by me or mailed to me by collaborators. Raw recording data in the form of WAC files (compressed audio files) were copied from SD cards to external hard drives for permanent storage. A backup copy of each external storage drive was made once the drive was full. Backups were stored at a different physical location from original storage drives.

WAC files are the raw data format created by the SM2 when data compression is used. The recorder creates a WAC file at regular time intervals, specified by the user. I chose an interval length of 15 minutes, in order to 1) limit the total quantity of WAC files created to a reasonable number that could be easily handled within the Windows environment (directories with more than

100,000 files can be difficult to work with in Windows), and 2) reduce the amount of data that would be lost if a recorder's battery ran out or otherwise stopped working in the middle of a recording interval. Each 15-minute WAC file contains one or more WAV sound files. The number of WAV files depends on the number of triggering events that occurred during the 15 minute interval. Regardless of the number of trigger events, the recorder creates a WAC file every 15 minutes while recording (between civil sunset and civil sunrise). This feature allowed me to know that the recorder was running even when no calls were being recorded, and this information was used to calculate the days and hours that each recorder was operational (i.e., differentiating between zero calls and no data).

Study Sites

Each study site was chosen to address a particular objective: fatality, landscape, before/after, or distance-to-turbine (Chapter 1, 2, 3, and 3 respectively). A map with all sites colored by primary objective is in Figure 2. Although each site is associated with a primary objective, information from many sites can be used to address multiple objectives. For example, data from all recorders was used to address questions about how call rates vary with distance from certain landscape features, and analysis for the distance-to-turbine objective involved both distance arrays and other wind farm recorders.

General descriptions of sites are given here, and full descriptions are provided in corresponding chapters. Detailed information on each site is included in Appendix A.

- The fatality study (objective 3) included 36 recorders at 8 wind farms where a fatality study (a research project including fatality searches, conducted independently of this project) either had been completed or was ongoing concurrently with this project. Between 4 and 8, and most commonly 4, recording sites were dispersed throughout each of the wind farms.

- The landscape study (objective 4) used recorders placed at several pre-specified distances from landscape features. These groups of recorders are referred to as "distance arrays". At forested river corridor arrays and grassland arrays, recorders were placed at 0, 200, 500, 1,500, and 5,000 meters from the edge of the selected feature, extending into adjacent agricultural land. At the Lake Michigan coastal arrays, recorders were placed within 500 m of the shoreline, and at 5, 10, and 16 km from the shore. Many additional recording sites were set up along the coasts of Lake Michigan, Lake Huron, Lake Erie, and Lake Ontario.

- For the before/after study (objective 5), recorders were located at prospective wind farms sites (sites where a wind developer was planning a wind farm, but had not yet built it). Four recorders were dispersed throughout each location. Three Minnesota wind farm sites (Paynesville near St. Cloud, Prairie Rose in Rock County, and Oak Glen near Owatonna) were studied prior to construction but only Oak Glen was studied post-construction, since it was the only site that completed development during this project.

- For the distance-to-turbine study (objective 6) recorders were placed at 50, 200, and 500 meters from the base of turbines. Four turbines at each of two wind farms (Fowler Ridge in Indiana, and Grand Meadow in Minnesota) were studied, involving a total of 24 recorders.

Data Processing

Data processing was conducted in two phases. Phase 1 was to identify any bat or bird calls in the recordings, and extract all pass files (files generated by a triggering event that contain one or more true bird or bat call(s)) for analysis and further processing. The goal of phase 2 was to identify the pass files to the most specific level possible (species, frequency group, etc.).

Phase 1 - Extraction of Passes

To process raw data files (WAC format) efficiently, they were first be decompressed to WAV sound files and then analyzed in WAV format. This meant that extra drive space was needed to hold the WAV files while they were processed. WAC files were stored on external storage drives and were decompressed to WAV format on internal processing drives in a series of computers. Internal drives were used for processing since processing is data-intensive, meaning the computer needs quick access to lots of data on hard drives. Internal drives (e.g., a standard C:\ drive on most computers) are mounted inside the computer frame and have a faster connection than the USB used by external drives. Over the course of the study I employed eight off-the-shelf PC's with Intel Core i7 or similar processors and minimum 1.5TB hard drive, and then added three 1.5TB internal hard drives to each computer, so each computer had four large processing drives (e.g., C, X, Y, and Z drives). The hardware setup was designed to maximize processing throughput. Since a single computer processor can run multiple instances of Song Scope (multiple windows open at the same time), but the program was heavily dependent on access to the data files stored on disk, I ran four instances of Song Scope on each computer, with each instance processing data from a different internal drive. This procedure helped limit data access

conflicts on the disks and increased the rate at which data could be made available to the processing software.

The computer analysis was conducted by two individuals (a data technician and myself) using a total of eight computers at two data processing stations. Data processing consisted of the following steps. 1) Decompression: A single data set (data from one SD card) of WAC files from storage drives was decompressed onto one of the four internal processing drives in one of the eight processing computers. 2) Processing: WAV files on the processing drive were analyzed by the Wildlife Acoustics Song Scope program, which used recognizer files (also referred to as "filters") I had made from bat and bird recordings from the first recording seasons (2010). To make the recognizers, manually identified calls were accumulated as training data and a recognizer file was generated using a set of parameters that best isolated identifying characteristics of the training calls. Hundreds of recognizers were created and tested before selecting the best-performing group of recognizers for processing. I used four recognizers concurrently for bats, and one catch-all recognizer for birds. The bird call recognizer was a nonspecific filter that registered any bird-like sound, including many non-bird noises, as potential calls. The bat recognizers also identified some non-bat noise as calls, but at a lower rate than that for birds. The output of processing was a long table of potential bat or bird calls identified in the recordings by the program. Each record in the output table includes information such as the time and site (recorder name) of the recording. 3) Visual verification: The spectrogram of each file containing one or more sounds detected by Song Scope was reviewed by eye and confirmed as either containing a true bird or bat call, or not, and marked in the output table with a Y or N accordingly. Results were saved as text files and later copied to spreadsheets in batches. Most further analyses were conducted with data from these spreadsheets. 4) Move confirmed calls: Using a batch command, each file with a confirmed bird or bat call was moved to a directory containing only confirmed pass files. Non-pass files were then deleted from the processing drive to free up space to process more data sets.

This processing cycle was run on each of the four processing drives concurrently, so that a total of 32 instances of the program (4 drives x 8 computers) could be run at the same time, and many data sets could be processed quickly. There are two main outputs from phase 1: 1) spreadsheets listing each confirmed bird or bat pass file and associated information such as recorder name, time and date, recognizer used, and duration of call, and 2) confirmed pass WAV files, initially

moved to a special directory on the processing drive, and then copied to dedicated drives containing only confirmed pass files for further analysis (e.g., species identification).

Phase 2 - Species Identification

Bats

This phase involved running all confirmed pass files from phase 1 through Wildlife Acoustics Kaleidoscope, an automatic species identification program. Verification of the automated process involved testing the program against a library of manually identified bat passes. Based on these tests, the detection and accuracy rates of the program were evaluated, and true species composition and pass counts were estimated.

Kaleidoscope can be configured to search for calls of a particular group of species by turning species-specific recognizers on or off. I utilized this feature by selecting only the species whose ranges (Harvey et al. 2011) overlapped with the recording location being analyzed. One exception to this operation was the inclusion of evening bat (*Nycticeius humeralis*) for sites in southern and central Minnesota and Wisconsin. The evening bat's range is generally considered to be south of this region, however many evening bat passes were identified during manual identification of recordings taken within this area.

Kaleidoscope can be run in one of three modes: "Sensitive," "Accurate," or "Sensitive/Accurate." Sensitive mode errs on the side of detecting more calls while allowing for more frequent misidentifications (less cautious), Accurate mode errs on the side of correctly identifying the species of a call while detecting fewer calls (more cautious), and Sensitive/Accurate is a middle ground between the two. I tested Sensitive and Accurate modes. More information on this process is in the following Analysis section.

The first step of species identification was evaluating Kaleidoscope's performance with a testing dataset of manually identified bat passes. Passes in the testing dataset were identified to species by two people independently and those identifications were considered to be accurate. This testing yielded rates of detection (the proportion of confirmed WAV files identified by the program as containing any bat calls) and accuracy (the proportion of species identifications that were correct) for the entire testing dataset, as well as for particular groups of passes (e.g., species or geographic region) within the testing dataset.

Additionally, results from testing were used to examine how Kaleidoscope output relates to the true species composition of a set of passes. This information was used to calculate species- and region-specific conversion factors for translating Kaleidoscope output into estimates of true species composition or abundance for the entire dataset of confirmed passes, or subsets of it.

Birds

I attempted to make species identification recognizers in Song Scope and Raven Pro (Cornell Lab of Ornithology), but was unsuccessful in creating recognizers that could reliably detect species or species groups. Other software I experimented with was unable to process large batches of data. Three major problems I faced were the vast diversity of bird sounds, the amount of noise present in the recordings, and the failure to collect many night flight calls. Individual birds can produce a variety of sounds (songs, call notes, chip notes), each of which have varying levels of complexity, and each of which would require a separate recognizer. Given the variation of calls within species and the large number of species, collecting enough training data for each type of vocalization became very difficult, even with a large and condensed data set. Ground-based recorders pick up a lot of noise, which fades signal edges and makes each contour of a call less likely to be recognized by the software. Even visual identification of calls in many of the pass files was challenging. Focusing on night flight calls meant sorting through hundreds of pass files before a useable training file was found. I ultimately decided that our efforts would be more productive identifying only bat calls to be used for thorough verification of the automated identification software. Bird passes were not identified to species or species group.

Analysis

Automated Species Identification

Bats

To evaluate Kaleidoscope's performance identifying species of bat passes, I tested the program with bat passes that had been manually identified. I took a random sample of 100 passes from each site for each year data was collected. The data technician and I attempted independently to determine the species identity of each pass by eye. The data technician had been trained to identify bat calls by sight in previous work experience. Only calls which we had both identified as the same species were kept for use in testing. We accumulated about 22,000 calls with which to evaluate Kaleidoscope. This group of passes is referred to as the "testing dataset."

Each pass file contains a series of one or more bat calls, or vocalizations. Each call is produced by a bat of a particular species, and generally the calling pattern within a pass file is consistent with the passing of a single bat through the microphone's reception range. In other words, most pass files contain calls from a single bat. I refer to the species of bat producing the calls in a pass file as the "true" identity of the pass file. Occasionally, multiple bats of different species are recorded in the same pass file. In these rare instances, the pass file has two true species identities. For manually identified pass files in the testing dataset, I assumed that the two-person verification process produced 100% accurate species identities, such that the true identity (or identities) was considered to be known for each of those 22,000 passes. Evaluation of the automated identification software was based on comparisons of known species identities to species identities assigned to pass file by the software.

Kaleidoscope assigns each pass either an automatic identification (AutoID) of a single species (e.g., EPFU for big brown bat) or NoID, which means the program was unable to assign a species identity. I refer to pass files classified as NoID by Kaleidoscope as "unidentified." I used only confirmed pass files (post-phase 1 data) with Kaleidoscope, meaning that I knew each pass file analyzed by Kaleidoscope had at least one bat call in it. Kaleidoscope does not differentiate between the inability to find any bat calls in a file and the inability to identify the species of calls in a file; both are classified as NoID. As such, detection rate was defined as the proportion of identified files (files assigned an AutoID) within a dataset of confirmed bat passes.

Files which were assigned a species identity by the program were either correctly identified or incorrectly identified. Correct identification meant that the AutoID matched the known identity, or matched one of the known identities in the case of multiple species in a single pass file. Incorrectly identified pass files are termed "misidentified." Accuracy rate was calculated as the proportion of correctly identified pass files among files that were assigned a species identity by Kaleidoscope (proportion of correct AutoID's). Unidentified calls do not factor in to accuracy rates.

Detection and accuracy rates based on a set of known pass files provide some indication of the program's performance, but they are not adequate for translating the program's output into estimates of true species composition or abundance given a set of unknown pass files.

Misidentified and unidentified pass files presented two separate but related challenges in estimating true species numbers within a data set from Kaleidoscope output.

Misidentified passes were accounted for by adjusting pass counts based on estimated multinomial distributions of true identities, given each automatic identity. The group of passes identified by Kaleidoscope as a particular species (e.g., AutoID = EPFU) comprises correctly identified files (true ID = EPFU) and misidentified files (true ID = LABO, LACI, etc.). True species compositions were estimated by treating the output of each AutoID species classification (e.g., 472 EPFU's) as a multinomial distribution over the sample space of true species identities found among the passes identified by the software (e.g., 385 EPFU's, 16 LABO's, 37 LACI's, etc.). This generated a different probability distribution for each species classification in the Kaleidoscope output, with standard errors based on the number of pass files assigned that species AutoID (e.g., n = 472). These distributions were used to produce estimates of true species pass counts based on Kaleidocope output.

The problem of unidentified calls was the biggest issue in the analysis since detection rates were mostly below 50% for both sensitive and accurate modes (Table 2). Unidentified passes could be treated in the same way as misidentified passes, however if over half of the calls in a given data set were unidentified, then the best-guess estimate of the true identity of those calls would be the known species distribution of unidentified calls in the testing dataset. The result would be that all unidentified the passes in any data set would be assigned an identical species composition (i.e., the composition of NoID's in the testing dataset). This washes out heterogeneity among sites, and especially among regions if a geographically non-specific subset of the testing dataset is used. Although I randomly selected 100 calls from each location each year for testing data, it is unlikely that the species distribution of those unidentified calls is representative of all unidentified calls from all locations. Using geographically specific subsets generates species compositions of unidentified calls that are likely more representative of sites in that region, but it also reduces sample sizes and increases uncertainty about the estimates, particularly for less common species and low-activity regions.

To investigate whether regional analyses would improve estimates, and also to assess the consistency with which Kaleidoscope performs across regions, I separated passes into eight groups by geographic region. I calculated true identity probabilities given Kaleidoscope output for each output species, separately for each region (Table 3). This approach resulted in more

realistic estimates, with sites retaining heterogeneity while maintaining adequate sample sizes for acceptable standard errors. Conversion factors based on these probabilities were used to convert Auto-ID output to estimates of true pass counts and species composition for sites based on region, with standard errors based on the number of true passes in the testing dataset from each species in each region. These estimates were used in further analysis of fatality, landscape, and wind farm effects analyses. Full results are included in Appendix C and the composition of the eight focal species within each region is illustrated in Figure 10.

Statistical Analyses

Procedures and Tools

Most analyses consisted of simple comparisons of pass rates or examination of relationships using regression with simple, multiple, or mixed effects linear models. Due to the skewed nature of pass counts and site means, many analyses were carried out with log-transformed pass counts or log-transformed means. The use of log transformations is discussed more in General Results. Summary statistics and less complicated calculations were carried out in Excel (Microsoft 2007). More complex calculations and modeling were performed in the program R (R Core Team, 2014) with functions ANOVA, AIC, lm (linear models), and lme (linear mixed effects models) in the package nlme (Pinheiro et al. 2014). Local regression curves were fitted using the program Arc (Cook and Weisberg 2004).

Adjustment for Seasonal Variation in Pass Counts

A general pattern in bat passes observed at every recording site was increasing pass rates throughout the spring and decreasing pass rates throughout the autumn. In most analyses, this trend is not of interest and contributes a large amount of unwanted variation to pass counts. Further, if data were collected at two sites or groups of sites across a different set of dates within the year, then the effects of site and date on pass rates may be confounded. Non-matching study periods were relatively common at collaborative sites with fatality searches, where study periods were usually in late summer and early autumn (e.g., July to October was a typical study period for fatality searches), when bat activity is high, and ignore early spring and late autumn, when bat activity is low. At non-collaborative sites, recorders operated according to the same schedule, which was intended to overlap with migratory periods (March 15 – June 1 and August 1 – November 15). Additionally, occasional equipment failure and logistical limitations meant that data collection was not necessarily consistent among all recorders in the field. If fewer recorders

were running during a particular part of the season, results may be biased as a result of seasonal activity patterns.

To account for this, I modeled the overall seasonal activity pattern of combined data from all recorders (or all recorders within a particular study where specified) and subtracted the mean seasonal pattern from pass counts to produce seasonally-adjusted (normalized) data sets. The procedure to model the pattern was to 1) convert pass counts to proportions within each site year by dividing each nightly count by the sum of all counts for that year at that site, then 2) find the mean proportion for each day of the year by averaging across all sites and years, and 3) fit a locally weighted regression (LOWESS) curve to the daily mean proportion (Figure 6). LOWESS was performed in program Arc (Cook and Weisberg 2004) with smoothing parameter 0.2, which was selected based on a visual assessment of the curve's approximation of the seasonal pattern. This produced a smooth curve that indicated the expected proportion of the year's passes that would be recorded on each day of the year.

To apply the adjustment to a group of sites, the daily proportion was multiplied by total pass count among the sites to be examined, giving the expected pass count for each day among those sites. This value was then subtracted from each site's actual pass count to give the seasonally adjusted pass count. This method of adjustment assumes that the seasonal pattern is similar at all sites. For example, if a site is less seasonal and has more consistent pass counts, the adjusted counts will indicate higher activity at the beginning and end of the season. The adjustment was applied to groups of sites per analysis, rather than across all sites at once, in order to isolate differences among specific locations or groups.

GENERAL RESULTS

We collected, processed, and verified about 1.7 million bat calls and 900,000 bird calls at 160 recording locations in the Upper Midwest and several other regions. Working with collaborators was hugely successful for expanding the geographic range of this project and collecting a data set that allows for comparisons of bat and bird activity at many geographic and temporal scales. A full list of bat and bird pass rates is included in Appendix B.

Summary	Bats	Birds
Passes Detected	1,738,332	901,825
Mean Pass Count	70.56	36.66
SD Pass Count	221.91	145.95
Median Pass Count	6	0
Nights Recorded	24,595	

Data Collection and Processing

Private landowners at most sites were very cooperative and willing to host a recorder on their property. Public agencies were also very cooperative and eager to learn about this research. Some wind farm operators were very cooperative and even let me place recorders on their rights of way. Others were less cooperative, in which case I contacted landowners directly for permission to place recorders. One benefit of this recorder's design is that it can be attached to most vertical structures, requires less rigging, and needs no additional weather protection, so it can be deployed almost anywhere and takes just a few minutes to set up at a field site. Although I attempted to place recorders a safe distance from the road, several were still easily visible, especially those in farm fields in the spring and after harvest in the autumn. Three recorders were lost to vandalism or theft.

The recorders performed relatively well during field deployments. The most common problem was broken microphones, which was exacerbated by the use of homemade ears, which could break the microphone if it became detached from the recorder. Microphones are easily interchangeable and were replaced immediately when found broken. Six recorders stopped working altogether, either during a field season or in between seasons. Internal batteries were less useful than external batteries, mainly due to the longer run time of external batteries, which meant less frequent maintenance trips, and enabled me to deploy recorders at additional locations. Recorders could be deployed 5 days on internal batteries and 10 days on external batteries. Many external batteries became damaged during the field seasons as a result of over-discharging during recording intervals longer than ten days. Powersonic batteries performed better than Werker brand batteries of the same specifications.

We amassed a dataset of raw sound files totaling about 80TB and ended up with about 12TB of confirmed bat and bird calls after processing. Data were stored and backed up on 2- or 3-TB

external hard drives. This was simpler and much cheaper than using a single large storage array. It also suited my purposes well, since the acoustic files were accessed only a few times in sequential order (e.g., for decompressing and processing) and did not need to be accessed readily throughout the process. The use of multiple processing computers each with multiple drives greatly increased processing throughput and allowed labor time to be maximized (i.e., we were not waiting for batches to finish processing).

The recognizers I made in Song Scope for phase 1 processing (extracting all bat and bird passes) were successful in catching most of the calls in the raw data. Testing indicated that about 80% of bird passes were caught using the single wide-net recognizer, and over 90% of bat passes were caught using the combination of four frequency-specific recognizers.

Pass Counts

Initial results from the first season of recordings at 19 sites indicated low bat and moderate bird activity in southwestern Minnesota and a wind farm in northern Iowa, and moderate to high levels of bat and bird activity at landscape arrays in south-central Minnesota. Recorders were added each subsequent season, and patterns began to emerge within the bat data while bird results were less conclusive. The addition of sites in the Great Lakes region greatly expanded both the footprint of the project and the range of activity rates observed. Among the first season's recordings, a night with 100 bat passes was considered very high, and this would have been the range of activity within which sites were compared if the project had not expanded. Great Lakes sites returned nights with 1,000 or more passes on a regular basis, and reclassified all of the initial findings as moderate to low activity (see Figure 3).

Nightly pass counts for both bats and birds were extremely right-skewed, with zeros accounting for 33% of nightly bat pass counts and 67% of bird pass counts. For bats, this was largely a result of seasonal fluctuation and long recording schedules, which began in mid-March before any activity had begun, and ended in mid-November after activity had concluded. This was a deliberate choice, so that the temporal gradient at the start and end of the activity period could be observed, but it resulted in many zero-pass nights at many recorders. When comparing bat activity among sites with slightly different start and stop dates, zeros that were recorded before the beginning or after the end of the activity period for some sites but not others were excluded from analysis to reduce downward bias for longer-running recorders.

For birds, seasonality and scheduling also had effects, but many sites had consistently low pass rates and counts of zero throughout the season. The recorders captured many fewer night flight calls, and many more morning and evening chorus calls and songs than I expected. Sites with substantial activity levels are dominated by post-sunset and pre-sunrise calling. Although they may not indicate the movement of migrating birds, these calls were included in further analysis because 1) they confirm the presence of birds, and can be used to quantify bird activity, even if the birds are not actively migrating, and 2) removing these "passes" resulted in very low numbers at most sites, and resulted in a data set with an overwhelming number of nights with zero passes. The time window between evening and morning chorus calling was surprisingly narrow at many sites, and unfortunately many of the true migratory pass calls are likely lumped in with or masked by chorus calls.

In addition to the many zeros, there are also extreme values, which account for the large differences between means and medians. I chose to do most analyses with means in order to include these extreme values. If the purpose of monitoring is to measure risk from wind turbines, then an extreme value may be indicative of high risk within that night, and should be included when trying to find a relationship to fatalities and assess relative levels of risk.

Log Transformation

Pass counts were so skewed that they produced means of relatively large samples (e.g., 300+ recorder nights for many sites) that were also heavily skewed. Most of my analyses used some kind of mean, primarily site mean, which is the average of all pass counts over the entire study period. There are 160 site means for bats and 144 for birds, since birds were not recorded at some locations. Accounting for the non-normality of means was important since they would be used in repeated comparisons and models. Neither Poisson nor negative binomial distributions, which sometimes approximate this type of data well (Alexander 2012, Xie et al. 2013), and would allow for distribution-specific mean comparisons and generalized linear modeling, were a good fit for mean pass counts. However, natural logarithm transformations produced distributions of site means that were close enough to normal to allow for the use of simple parametric comparisons and models. The results of this transformation are illustrated in Figure 4. In formal analyses using individual pass counts, which frequently contained zeros, the transformation consisted of adding one to the pass count and then taking the natural logarithm.

Temporal Variation

Pass rates from all locations were highly variable from night to night, but also followed a general pattern of increasing activity in the spring, and decreasing activity throughout the autumn (Figure 5). The within-night pattern was bimodal, with the highest peak about an hour into the night and another lesser peak about an hour before civil sunrise (Figure 7).

Species Identification

The evaluation of Kaleidoscope for phase 2 processing (species identification of bat calls) resulted in mixed findings. I tested Accurate and Sensitive modes in Kaleidoscope on a library of about 22,000 manually identified passes. There were sufficient sample sizes to test performance for eight species, referred to as the "focal species": big brown bat (*Eptesicus fuscus,* EPFU), eastern red bat (*Lasiurus borealis,* LABO), hoary bat (*L. cinereus*, LACI), silver-haired bat (*Lasionycteris noctivagans,* LANO), little brown bat (*Myotis lucifugus,* MYLU), northern long-eared myotis (*Myotis septentrionalis,* MYSE), evening bat (*Nycticeius humeralis,* NYHU), and tricolored bat (*Perimyotis subflavus,* PESU).

Detection and accuracy rates were assessed for both Sensitive and Accurate modes, with error based on sample sizes of true passes in the testing dataset. These results are listed in Table 2, and differences between the two modes are illustrated in Figures 8 and 9. Detection and accuracy rates cannot be combined to generate an estimate of the number of bats per species based on Kaleidoscope output, since the species composition of unidentified calls (NoID's) is not known. Sensitive mode was found to improve detection rates substantially without sacrificing much accuracy. For this reason, sensitive mode was determined to be more suitable for the purpose of finding large-scale patterns among many passes of common species. Sensitive mode was used for all analyses of confirmed passes. Estimates of species composition and abundance are also based on output using Sensitive mode.

After initial evaluation of the performance with the entire testing dataset, I found that the program's identification of species was inconsistent among geographic regions. As a result, I carried out both the evaluation of Kaleidoscope's performance within the testing dataset (Table 3, Figure 9), and estimation of true species composition (Figure 10) separately for eight geographic regions: Eastern U.S., Lake Erie, Lake Michigan, Eastern Wisconsin, Central Minnesota, Southern Minnesota, Southwestern Minnesota, and Texas (a full list with regions for each site is

included in Appendix A). Full species analysis was carried out with only the eight focal species listed above, even though several regions host additional species, particularly the Texas wind farms. Estimates of species composition do not incorporate the total species richness for these areas, but rather report the relative proportions among only the eight focal species within the region.

This process resulted in eight geographically-specific sets of conversion factors that could be used to translate Kaleidoscope output into estimates of true species composition among the eight focal species. Additionally, species-specific pass rates were estimated in regions where most common species were well represented in the testing process. Species-specific count estimates were used in further analyses of the relationship between pass rates and fatalities, landscape features, and wind farms. Each site's estimated species pass counts and average pass rates are in Appendix C.

Further results apply to specific research objectives, and are contained in the following chapters. A General Discussion and General Conclusion are at the end of this document.

Figure 2: Recording sites color-coded by primary research objective. A total of 160 recording sites were used. Most locations contain three or more recording sites, represented by overlapping dots. Each location was selected to address a particular research objective. Fatality sites are associated with objective 3 (Chapter 1), Landscape sites and USFWS Great Lakes sites with objective 4 (Chapter 2), Before/After sites with objective 5 (Chapter 3), and Distance-to-Turbine sites with objective 6 (Chapter 3). Full lists of sites with coordinates, regional classifications, mean pass rates and other attributes are in Appendices A and B.
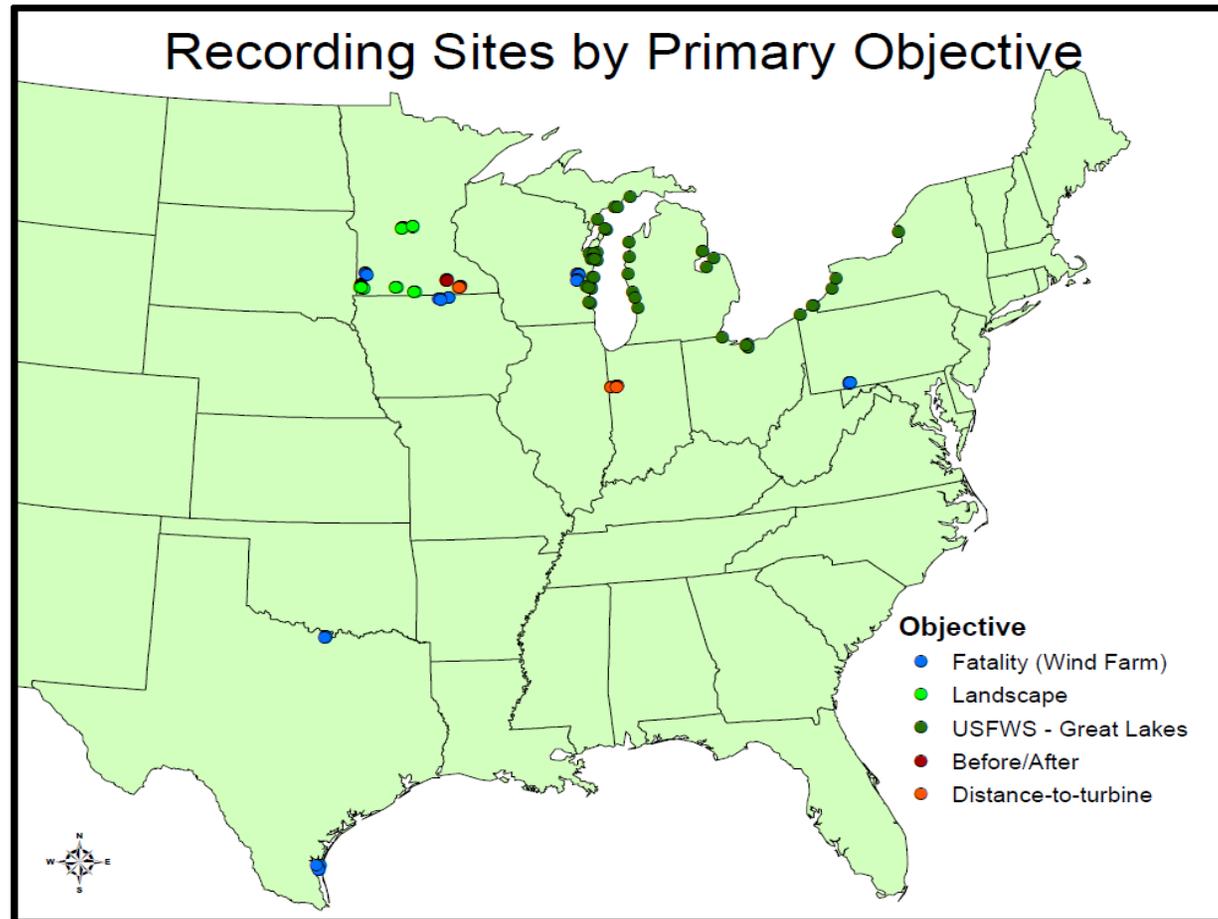
Figure 3: Recording sites with location dot sized by mean nightly pass count (site mean). High activity levels are apparent in the Great Lakes region.
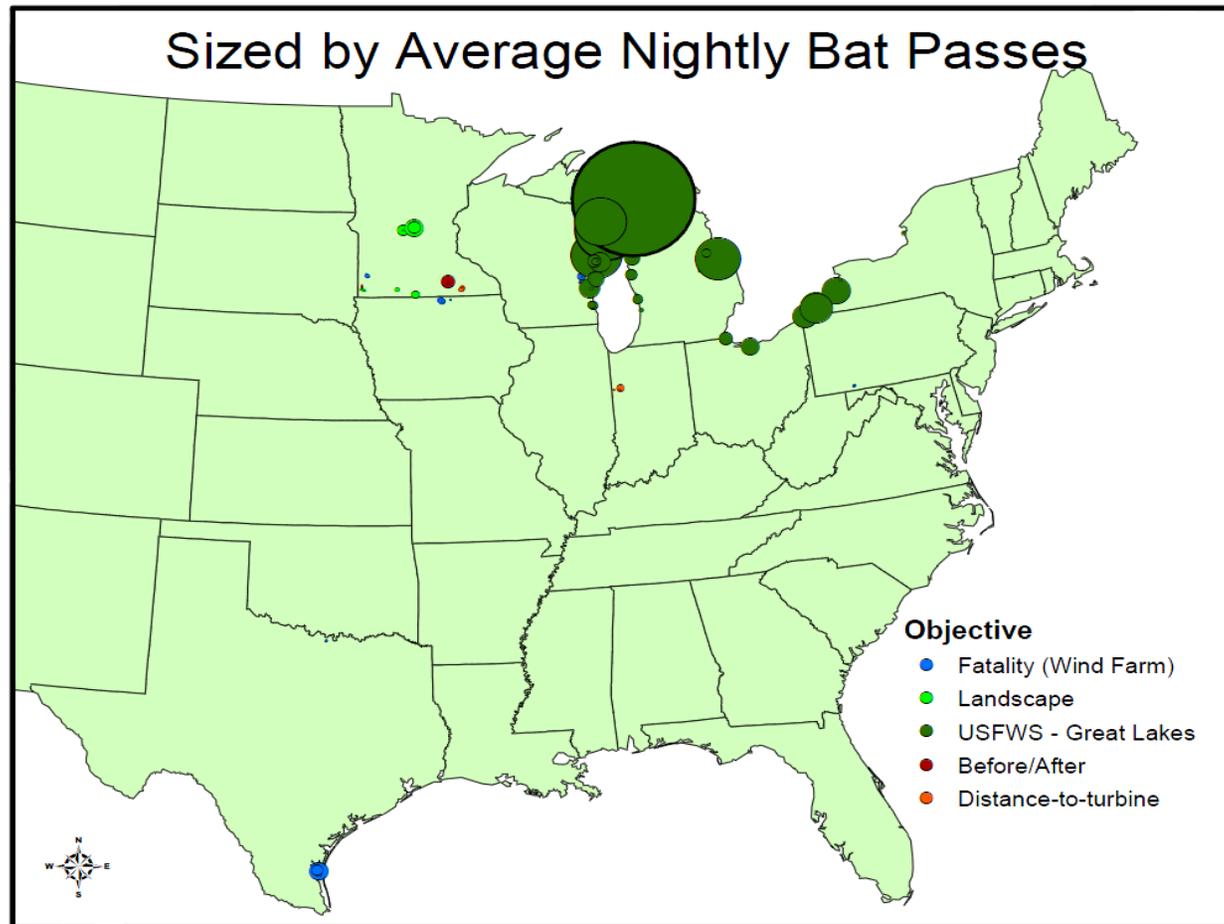
Figure 4: Natural logarithm transformation of site means (mean of all nightly pass counts) for bats (a) and birds (b) by natural logarithm for use as response variable in statistical analyses. Untransformed site means are heavily skewed and are not well approximated by Poisson or negative binomial distributions. A log transformation produced values appropriate for simple analyses which assume normally distributed response values.

(a)
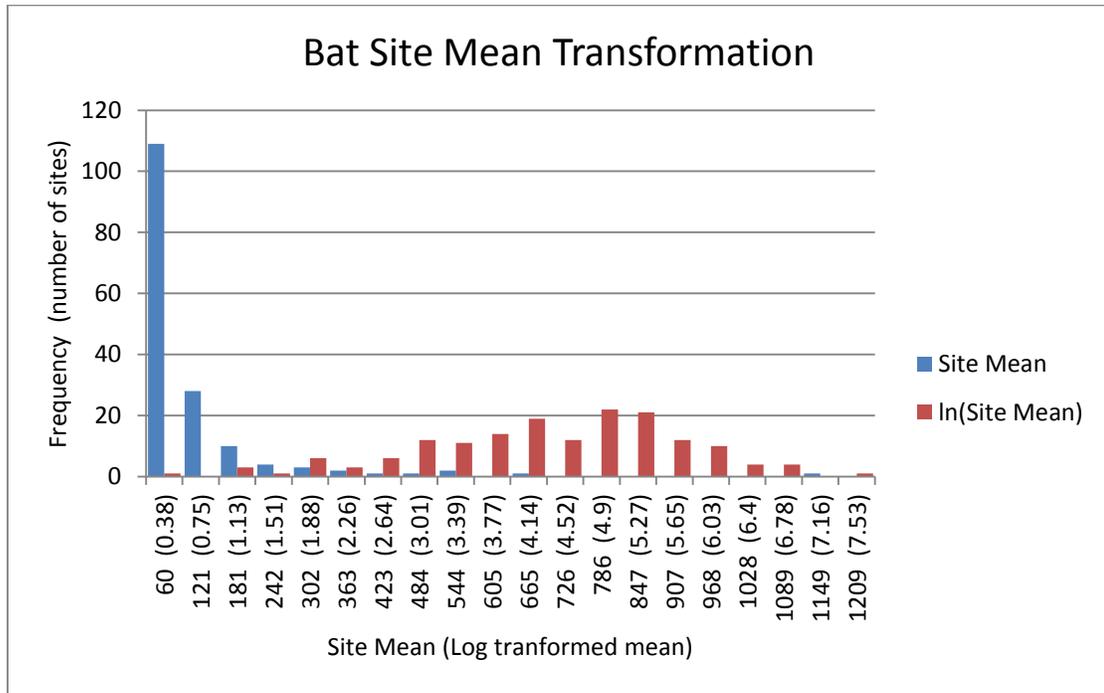
(b)
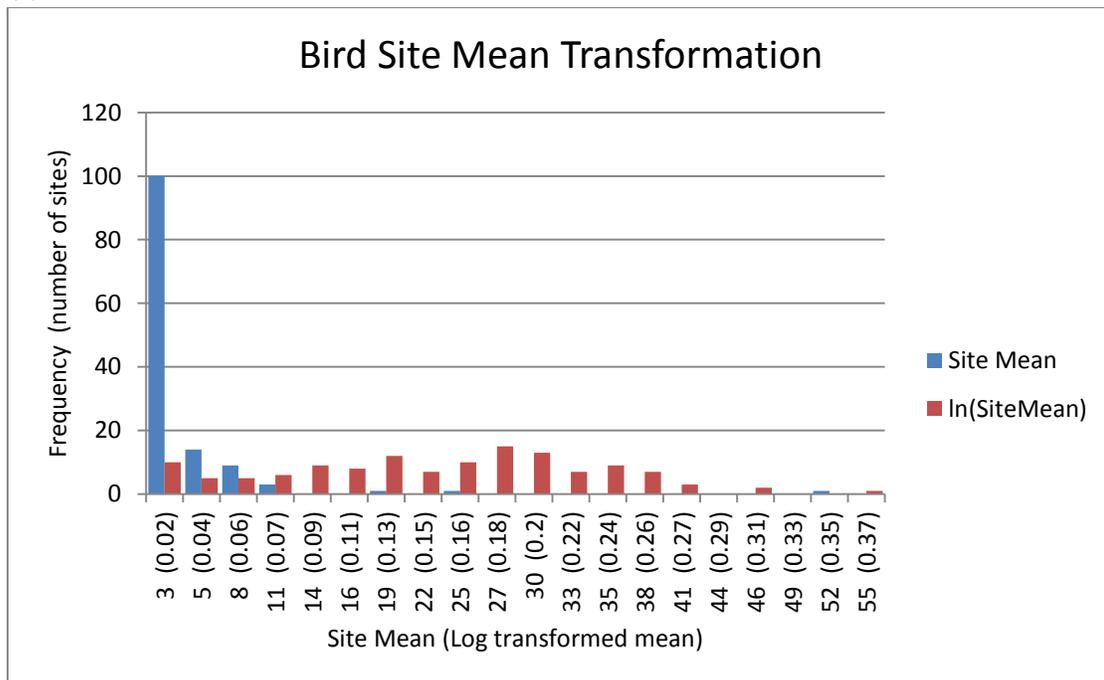
Figure 5: Seasonal variation in bat pass rates. Each bar represents a 10-day average of pass counts, centered on the date listed. Temporally varying pass rates presented a problem when different data collection timeframes were used, for example at sites where collaborators were maintaining recorders. Pass rates in 2012 are higher due to the inclusion of Great Lakes sites, which had higher activity levels than other sites, which inflated overall daily pass rates.
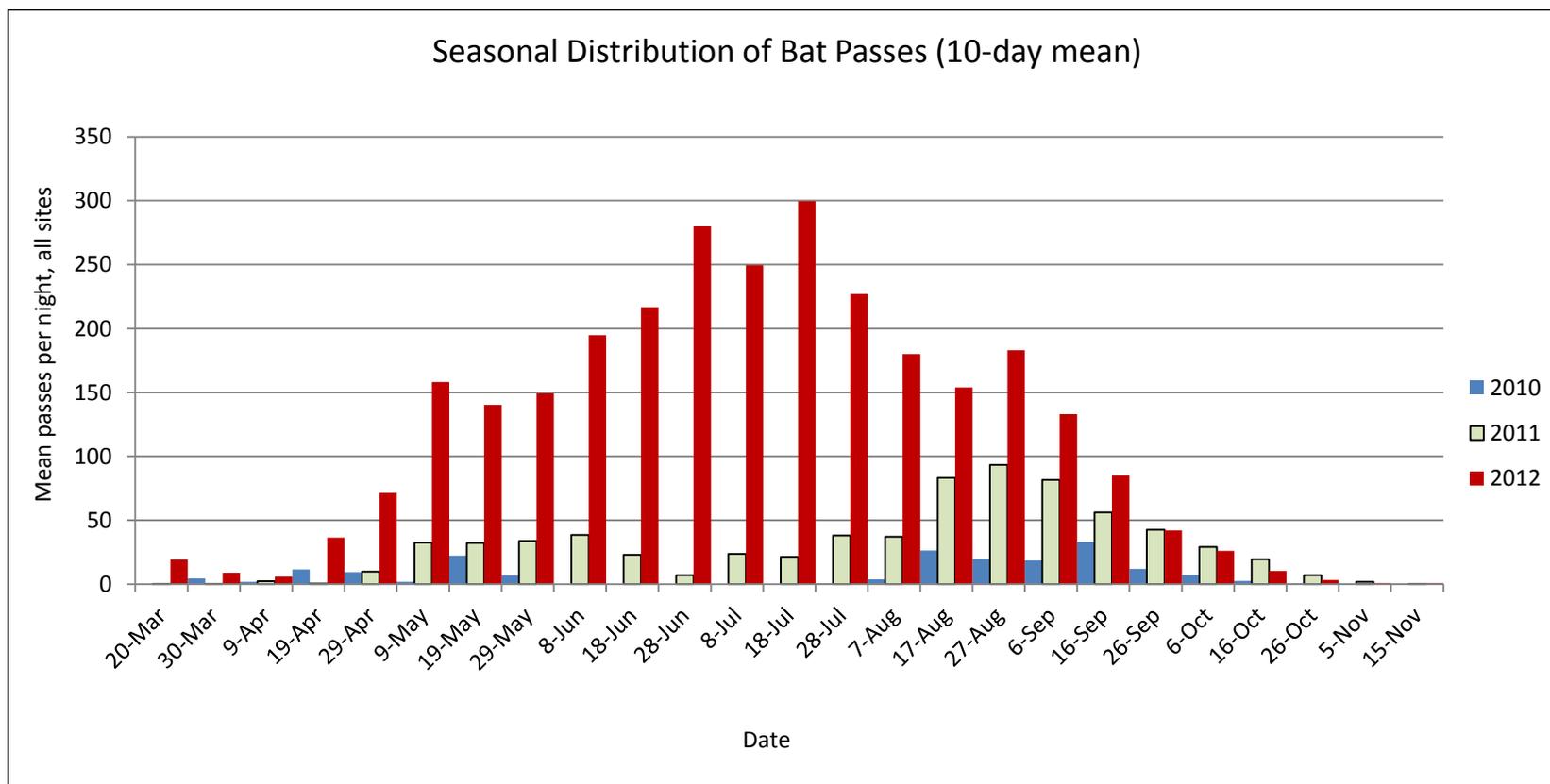
Figure 6: LOWESS curve fitted to the mean nightly proportion of pass counts. The blue line represents the average portion of all calls collected on each night. The red line is a locally weighted regression curve approximating the seasonal pattern. This curve was used to adjust nightly pass counts when analyzing data from sites with non-overlapping data collection periods. A smoothing parameter of 0.2 was used to fit the curve in the program Arc (Cook and Weisberg 2004).
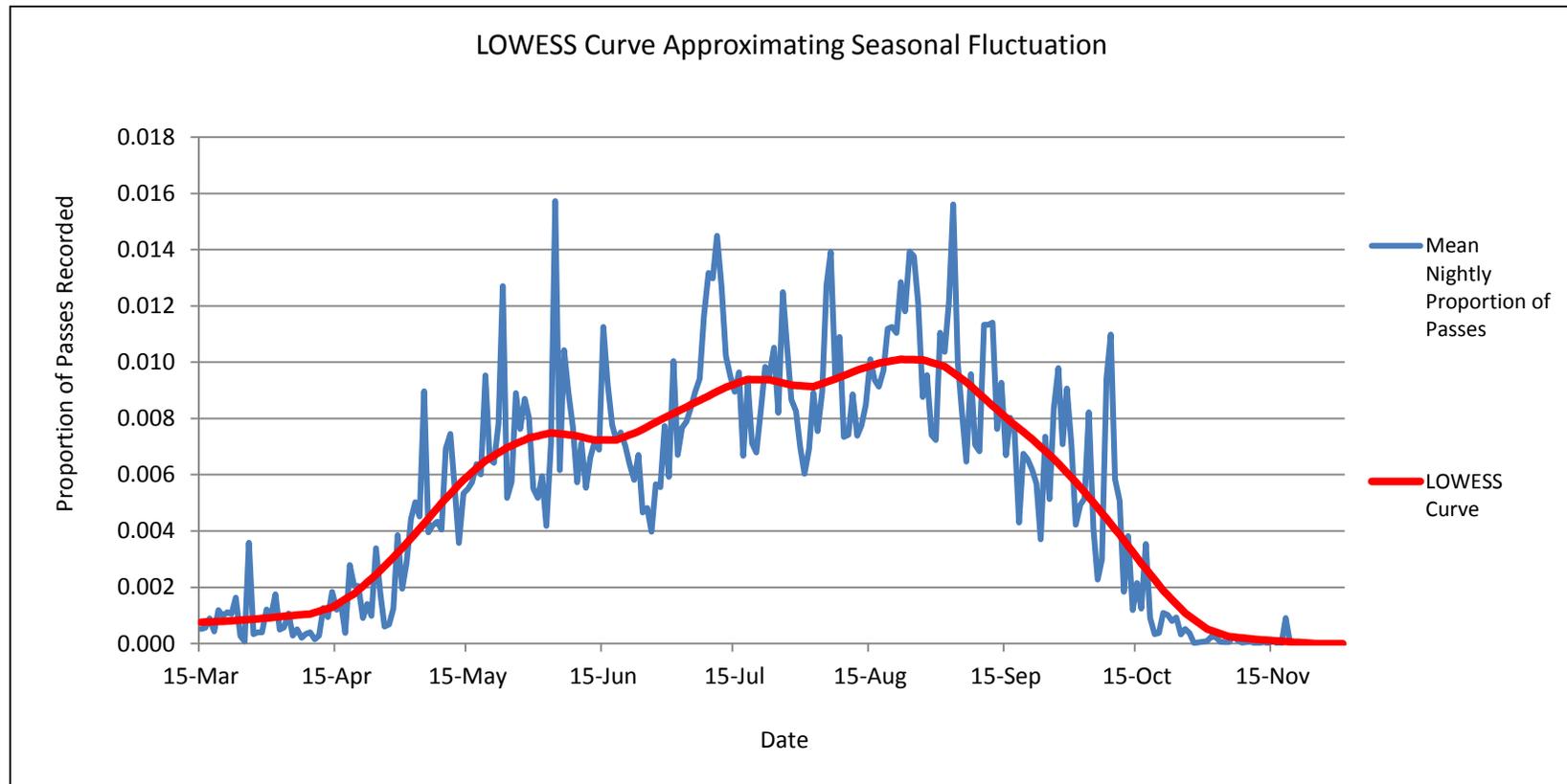
Figure 7: Within-night variation in pass rates. Acoustic activity is slightly bimodal, with a more distinct peak early in the evening following a steep increase after sunset, and another peak prior to sunrise followed by a more gradual decrease in activity.
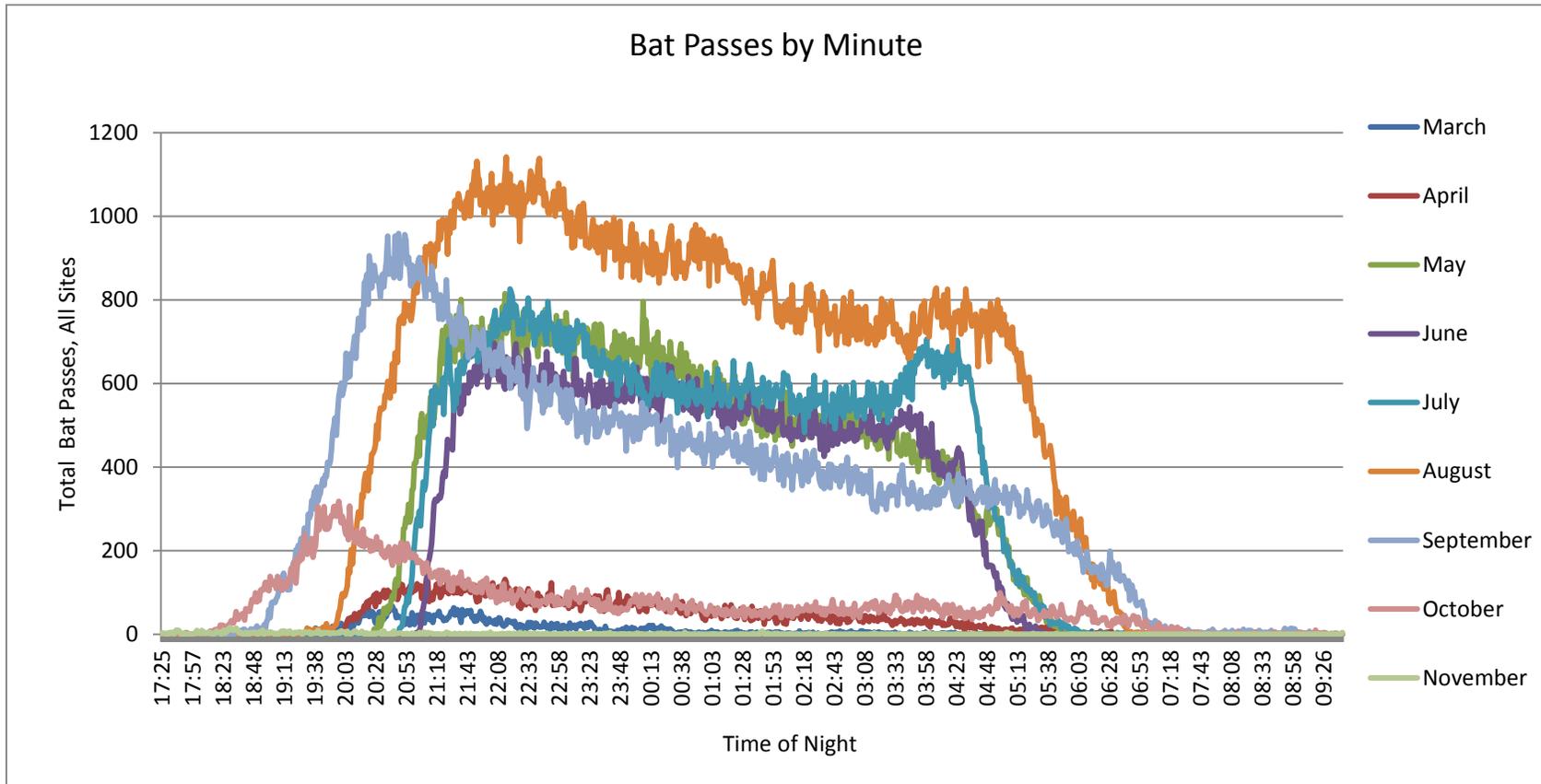
Table 2: Detection and accuracy rates for Kaleidoscope using Sensitive and Accurate modes. These are based on a sample dataset of 22,968 known (manually identified) passes. Kaleidoscope returns either a species ID (EPFU, LABO, etc.) or a classification of "NoID" for each pass. Detection rate (a) is the proportion of passes to which Kaleidoscope assigned a species ID, given a set of known calls of a particular species. Accuracy rate (b) is the proportion of those identified calls that were assigned the correct species identity. For my purposes, sensitive mode was preferable because it identified more passes despite being more error-prone. N/A for Mexican free-tailed bat in (b) is due to a sample size of fewer than 50 automatically-identified TABR passes. Standard errors (SE) of estimates are small due to large sample sizes.

(a)

Detection Rates				
Mode	Sensitive		Accurate	
Spp. (manual ID)	Estimate	SE	Estimate	SE
EPFU	56.41%	1.27%	12.22%	0.84%
LABO	61.84%	1.62%	34.85%	1.58%
LACI	26.05%	0.56%	10.69%	0.39%
LANO	38.77%	1.17%	13.65%	0.82%
MYLU	56.81%	0.70%	28.18%	0.63%
MYSE	58.24%	5.17%	26.37%	4.62%
NYHU	45.38%	0.91%	12.90%	0.61%
PESU	24.54%	0.97%	6.10%	0.54%
TABR	22.70%	3.28%	15.95%	2.87%

(b)

Accuracy Rates				
Mode	Sensitive		Accurate	
Spp. (AutoID)	Estimate	SE	Estimate	SE
EPFU	63.34%	1.64%	86.52%	0.94%
LABO	31.57%	1.97%	34.12%	2.70%
LACI	92.88%	0.64%	92.08%	0.36%
LANO	41.50%	1.90%	56.56%	1.58%
MYLU	91.48%	0.52%	93.36%	0.36%
MYSE	10.64%	4.24%	24.42%	9.11%
NYHU	81.04%	1.06%	93.55%	0.46%
PESU	82.11%	1.75%	87.80%	0.79%
TABR	n/a		n/a	

Figure 8: Trade-off between accuracy and detection for Sensitive vs. Accurate mode, by focal species. Switching from Sensitive to Accurate mode causes many fewer calls to be identified, but does not dramatically improve the accuracy of those identifications. Accurate mode may be more appropriate if the objective is finding calls of a particular species of interest. However, my purpose was to identify many passes and establish relative abundances of common species with as much precision as possible. I also had the ability to examine identification patterns with a library of know passes. For these reasons, I chose Sensitive mode for my analyses.
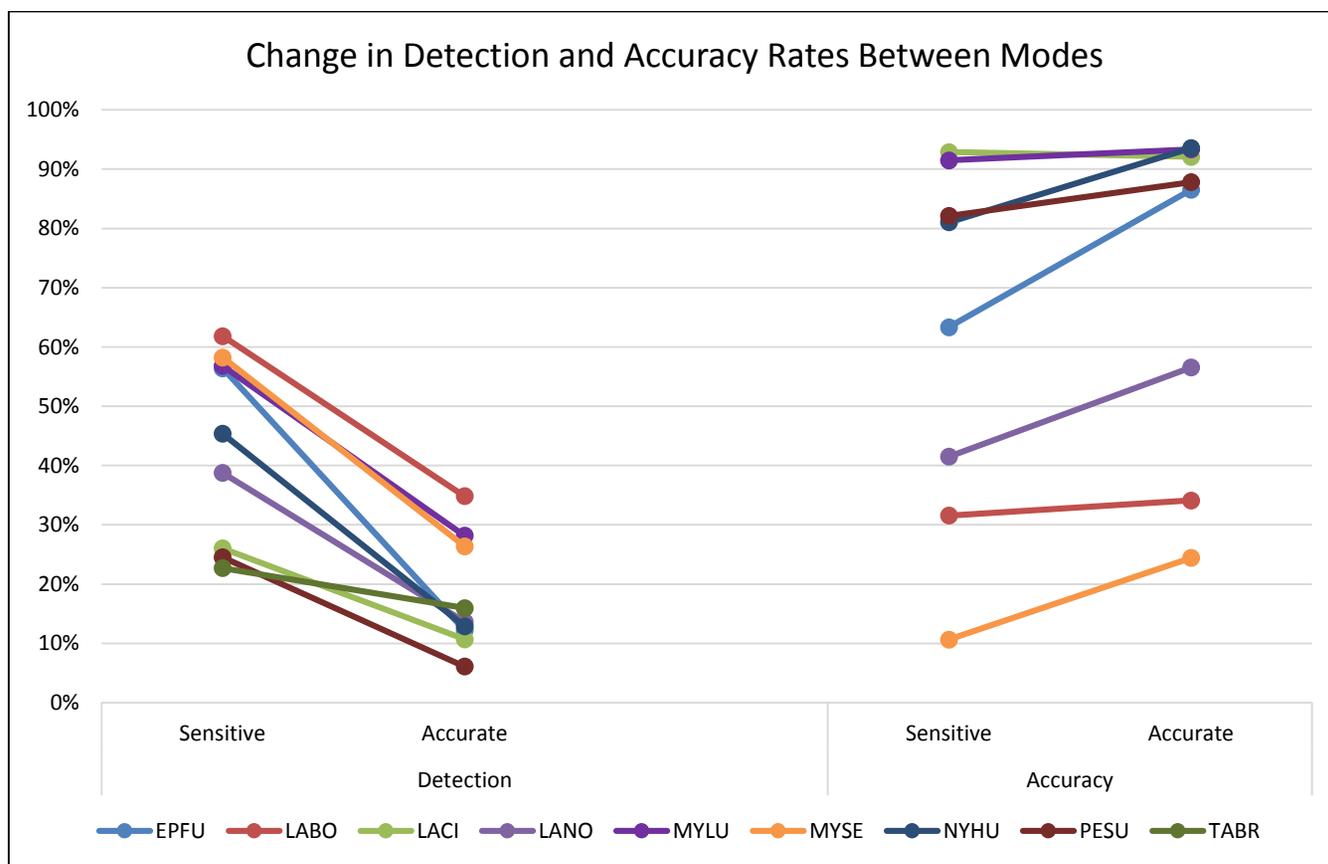
Table 3: Species composition of the eight focal species within the sample data set used to test Kaleidoscope (22,968 pass files), as estimated by Kaleidoscope using Accurate mode (a), Kaleidoscope using Sensitive mode (b), and manual visual identification (c). Manual identities were assumed to be accurate, since only passes verified independently by two individuals were included. There is no NoID classification for manually identified passes as unidentifiable passes were excluded from the testing dataset. MS = Minnesota southern, LM = Lake Michigan, LE = Lake Erie, WE = Wisconsin eastern, EA = East (Pennsylvania and Indiana), TX = Texas (southern and northern combined), MC = Minnesota central, SW = southwest Minnesota.

(a)

NoID	82.81%	85.55%	81.50%	86.24%	87.55%	76.17%	87.78%	63.76%
Accurate	MS	LM	LE	WE	EA	TX	MC	SW
EPFU	0.38%	0.96%	0.89%	0.45%	0.25%	0.16%	0.50%	1.04%
LABO	3.51%	2.47%	2.78%	2.84%	7.00%	8.93%	0.94%	1.63%
LACI	2.61%	1.78%	1.61%	4.52%	1.85%	0.43%	6.28%	4.22%
LANO	1.29%	1.93%	1.44%	0.90%	1.15%	0.11%	3.17%	3.34%
MYLU	8.98%	6.61%	10.22%	4.39%	1.35%	0.81%	1.22%	0.17%
MYSE	0.36%	0.61%	0.83%	0.52%	0.30%	0.00%	0.11%	0.00%
NYHU	0.05%	0.09%	0.11%	0.13%	0.20%	12.21%	0.00%	0.21%
PESU	0.02%	0.00%	0.61%	0.00%	0.35%	1.18%	0.00%	0.00%

(b)

NoId	58.28%	63.81%	58.11%	62.34%	61.05%	51.62%	66.00%	63.76%
Sensitive	MS	LM	LE	WE	EA	TX	MC	SW
EPFU	3.74%	4.58%	4.61%	6.78%	4.10%	0.95%	5.72%	7.64%
LABO	5.96%	3.96%	4.56%	3.75%	6.80%	8.44%	1.39%	2.55%
LACI	4.35%	3.12%	3.33%	7.62%	2.50%	0.80%	11.22%	7.18%
LANO	4.63%	5.68%	4.67%	3.94%	4.60%	0.58%	8.17%	9.39%
MYLU	16.15%	11.27%	16.33%	10.59%	6.95%	2.81%	3.39%	2.51%
MYSE	2.47%	2.06%	2.39%	2.26%	1.40%	0.53%	0.50%	0.29%
NYHU	3.69%	4.97%	3.61%	2.13%	9.45%	28.81%	2.94%	5.39%
PESU	0.73%	0.56%	2.39%	0.58%	3.15%	5.46%	0.67%	1.29%

(c)

Manaul	MS	LM	LE	WE	EA	TX	MC	SW
EPFU	6.32%	8.66%	6.91%	8.87%	8.95%	6.69%	3.46%	9.32%
LABO	4.12%	3.39%	3.02%	5.61%	3.63%	8.09%	7.29%	2.58%
LACI	28.27%	29.30%	23.99%	37.70%	45.62%	20.41%	7.51%	52.79%
LANO	7.30%	9.15%	5.59%	7.83%	13.90%	7.10%	1.72%	14.22%
MYLU	35.90%	26.25%	35.74%	25.64%	7.45%	22.53%	14.03%	10.55%
MYSE	0.26%	0.73%	1.01%	1.32%	0.00%	0.07%	0.12%	0.06%
NYHU	9.18%	13.09%	9.42%	4.16%	13.40%	23.40%	51.29%	5.95%
PESU	8.64%	9.43%	14.32%	8.87%	7.04%	11.70%	14.58%	4.54%

Figure 9: Graphical representation of species composition of eight focal species in the testing dataset as determined by Kaleidoscope (Accurate and Sensitive modes) and manual identification. SW = southwest Minnesota, MC = Minnesota central, TX = Texas (southern and northern combined), EA = East (Pennsylvania and Indiana), WE = Wisconsin eastern, LE = Lake Erie, LM = Lake Michigan, MS = Minnesota southern.
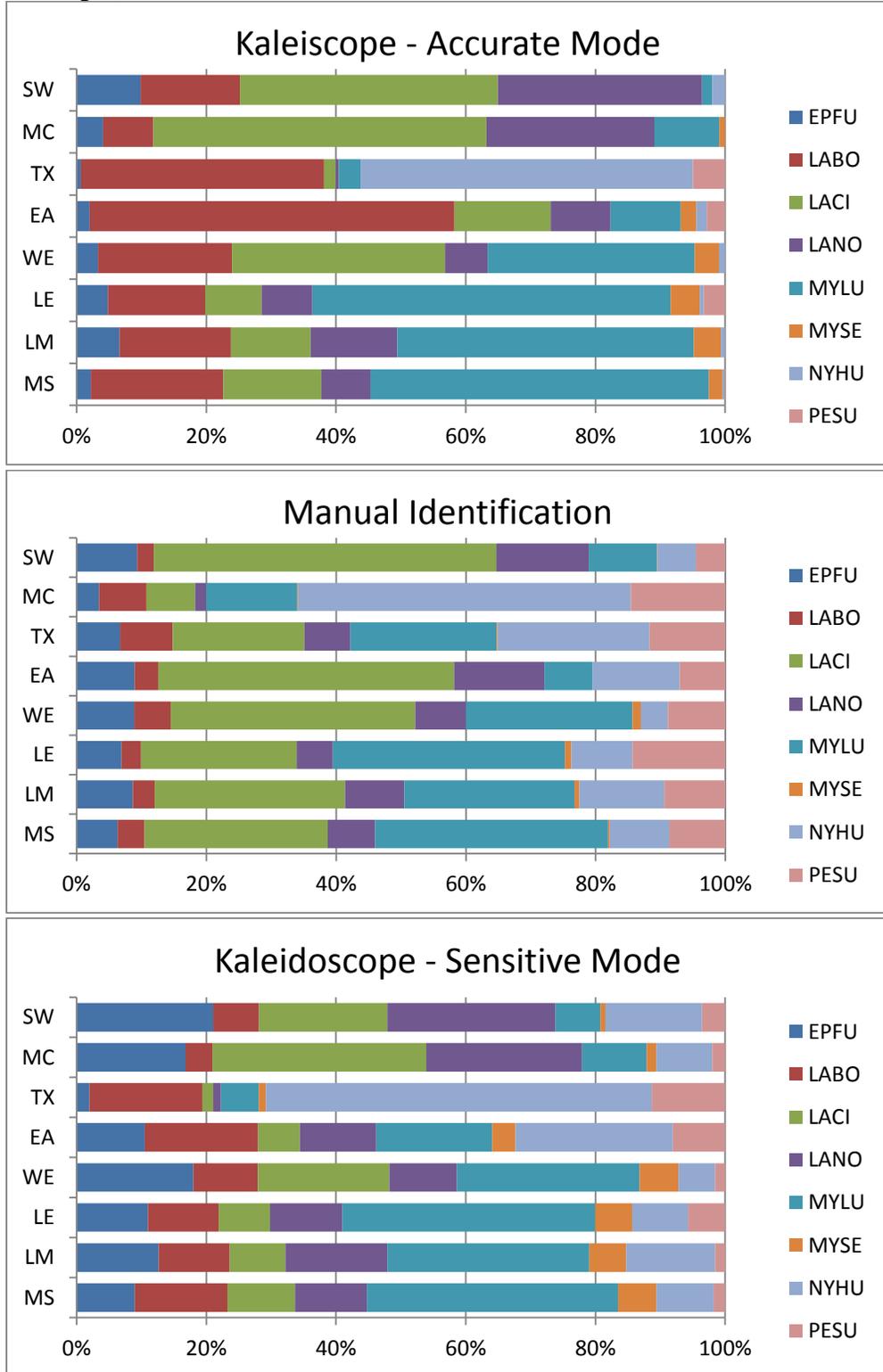
Figure 10: Estimated species composition of the eight focal species among all passes identified by Kaleidoscope (AutoID's, not including NoID's). These proportions are based on the all confirmed pass files, not just sample data. Kaleidoscope output was translated into estimates of true species proportions using conversion rates derived from the results of the testing process. EA = East (Pennsylvania and Indiana), LE = Lake Erie, LM = Lake Michigan, MC = Minnesota Central, MS = Minnesota Southern, SW = Southwest Minnesota, TX* = Texas (southern and northern combined), WE = Wisconsin Eastern. Numbers in parentheses are the number of recording sites in that region.

Estimated Relative Species Proportions Among Eight Focal Species, by Region
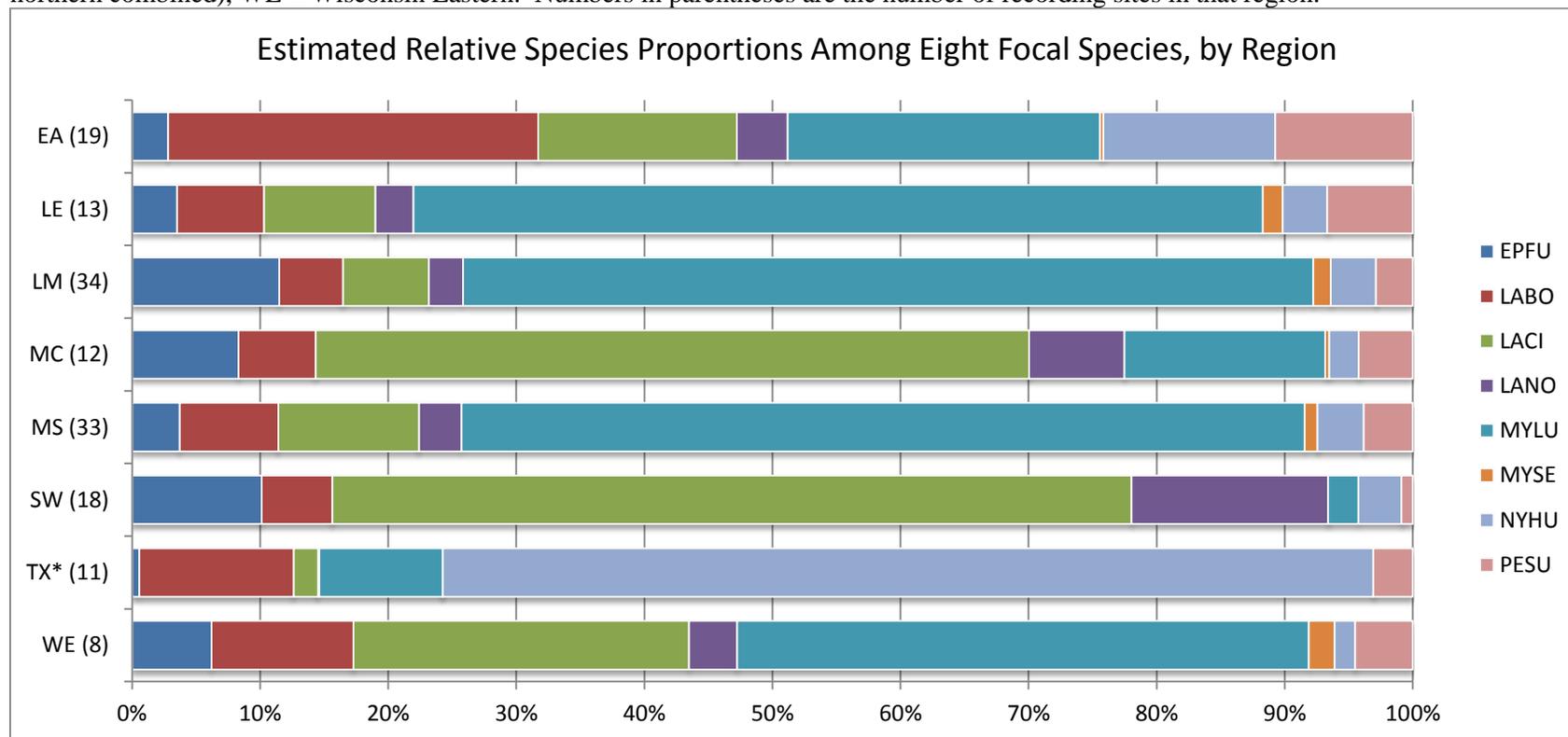
*Texas has much higher bat species diversity than other regions. These data include only the eight focal species encountered frequently in the Upper Midwest, so these proportions likely do not reflect the true species composition of bat passes recorded at sites in Texas. The Texas region comprises two locations with very different species profiles, Wolf Ridge in northeastern Texas and Penascal along the southern Gulf Coast. These proportions may not accurately reflect the species composition of either location, even among the eight focal species.

Chapter 1: Relationship between Bat Pass Rates and Fatalities

Introduction

Research into bird fatalities at wind farms in the U.S. began in the late 1980s (Orloff 1992) at Altamont Pass, California, but bat fatalities were not recognized as a potential problem until substantial numbers were found at the Montaineer wind farm in West Virginia (Kerns and Kerlinger 2004) and Buffalo Mountain in Tennessee (Fiedler 2004). Bat fatalities are a relatively unusual occurrence in most fatality events at communication towers, where migrating bird fatalities are much more common (Avery 1978, Orbach and Fenton 2010). First thought to be mainly associated with wind farms built along forested ridge tops in Appalachia and the Mid-Atlantic, bat fatalities have since been found in a wide variety of settings throughout the United States and elsewhere (Arnett and Baerwald 2013).

Estimated fatality rates vary dramatically among sites (Arnett et al. 2008), indicating that the location of a wind farm may be one determinant of fatality levels. However, no clear geographical patterns have yet emerged to help guide wind farm siting. A lack of quantitative data regarding the geographic distribution of bats and their daily and seasonal movements is a contributing factor to this problem.

Recent research aimed at reducing impacts to bats has uncovered several patterns that facilitate a basic understanding of bat fatalities at wind turbines. Migratory tree-roosting bats are found more commonly than other species during fatality searches (Johnson 2005, Arnett et al. 2007). These species travel long distances (> 800 km; Fleming and Eby 2003, Cryan 2004) in the spring and autumn to find suitable winter climates rather than hibernating, and generally use trees to roost rather than caves. In the Upper Midwest, three long-distance migrants are common during the summer: the hoary bat (*Lasiurus cinereus*), eastern red bat (*L. borealis*), and silver-haired bat (*Lasionycteris noctivagans*).

Another common thread among fatalities is strong seasonality. Almost all fatalities occur in the late summer or early autumn (Arnett et al. 2008). Mating occurs during this time period, as well

as the beginning of migratory journeys, either in the form of long-distance migration for the tree-roosting species mentioned above or shorter regional movements to hibernacula for hibernating bats. Mating, migration, or both may influence behavior or movement patterns in a way that increases the likelihood of a collision (Cryan and Barclay 2009).

The overrepresentation of migratory tree-roosting species and temporal clustering of fatalities has spurred conjecture regarding the relation of the common life history traits of these three species to possible mechanisms of collisions. Some of these explanations have been summarized as formal hypotheses by Kunz et al. (2007) and Cryan and Barclay (2009). Many hypotheses involve the possible attraction of bats to wind turbines, and several rely on seasonal migration or mating behavior to explain collisions.

While temporal and taxonomic patterns among fatalities have emerged, the spatial distribution of fatalities remains less clear. Some regions appear to have consistently low fatality rates, but much of the country has rates that vary widely (Hein et al. 2013). The goal of this study was to examine the relationship between activity measured by acoustic recorders and fatality rates. If a strong relationship was found, acoustic monitors could potentially be used to estimate collision risks at prospective wind farm sites prior to development. This would allow government agencies, wind energy developers, and consultants to identify sites with low fatality impact potential, and encourage development at those sites.

There appears to be an interaction between bats and wind turbines that can result in high fatality rates at wind energy facilities. For this reason, my primary focus was on examining the pass rate-fatality rate relationship for bats rather than for birds. When searching for study sites that had previous or ongoing fatality searches, I focused on finding wind farms with bat fatality data. These studies did not always have bird fatality data, and there were not enough sites with bird data to carry out an analysis of the relationship between pass rates and fatality rates for birds.

Methods

Acoustic recorders may be able to predict fatality risk if there is a strong relationship between acoustic activity levels and fatality levels among wind farms. I found eight wind farms where bat fatality studies had either been completed, or were underway, and deployed recorders at those locations to measure bat activity. Acoustic activity levels were then compared to fatality levels in

a regression analysis to find the relationship between activity rates and fatality rates. A strong relationship would provide support for the possibility of using acoustic monitors to aid wind farm site selection.

Study Sites

Wind farms were selected if fatality data for the facility existed in published or gray literature (non-peer reviewed reports by environmental consultants) or if a fatality study was ongoing at the facility. The wind farm either had to be within reasonable distance from Minneapolis or have teams conducting fatality searches who were willing to collaborate and perform recorder maintenance and data collection for this study. Fatality data taken from literature (e.g., Jain 2005) were collected prior to this project, meaning acoustic recording would not be conducted concurrently with fatality searches. Sites with prior studies were judged to be appropriate for use in this analysis for two reasons: 1) wind turbine model, location, and operation were assumed to be unchanged between their fatality study year(s) and my acoustic recording years, meaning that the probability of fatalities not associated with temporal variations such as weather should also be consistent, and 2) the application of this method does not require concurrent data collection, since predictions of fatalities would necessarily be based on recordings from years prior to development.

Collaborative study sites were found by networking with other wind-wildlife researchers. Collaborators managed the recorders during the study period, including replacing data cards and charging batteries in exchange for access to collected acoustic data. I travelled to collaborative study sites at the beginning of the study period to set up recorders, and returned to collect the equipment at the end of each season. During the study, collaborators mailed data cards to me, and I returned blank data cards to them.

Table 4: Wind farm study sites, with collaborators where indicated. BCI = Bat Conservation International, WEST = Western Ecosystems Technology Inc., and TCU = Texas Christian University.

Wind Farm	Location	Recorders	Recording Periods	Collaborator
Blue Sky Green Field	Wisconsin	4	Spring and autumn 2011 and 2012	
Buffalo Ridge	Minnesota	3	Spring and autumn 2011 and 2012	
Casselman	Pennsylvania	8	Autumn 2011	BCI
Cedar Ridge	Wisconsin	4	Spring and autumn 2011 and 2012	

Fowler Ridge	Indiana	12	Summer-autumn 2012	BCI
Penascal	Southern Texas	8	Autumn 2011	WEST, BCI
Top of Iowa	Iowa	4	Spring and autumn 2011 and 2012	
Wolf Ridge	Northern Texas	4	Summer/autumn 2010, 2011 and 2012	TCU

Each wind farm is described here, and details about each recorder site are in Appendix A.

- Blue Sky Green Field is a wind farm completed in 2008 with 88 turbines and a generating capacity of 145 megawatts (MW) operated by We Energy. It is just east of Lake Winnebago, on the west side of the Niagara Escarpment in east-central Wisconsin. Turbines are as close to the lakeshore as 2.5 km in the wind farm's northwest corner, but most of the western edge of the facility is more than 5 km inland. It is a mostly agricultural setting with many hills and a few patches of forest around the edge of the wind farm. Turbines are placed sporadically, generally in the middle of large fields, and the project is an irregular shape about 50 km^2 in area. The fatality study was carried out by an environmental consultant, with searches during the autumn of 2008 and spring of 2009 (Gruver et al. 2009). The report was completed in December 2009 and made public by the Public Service Commission of Wisconsin.

- Buffalo Ridge is a sprawling wind energy project in southwestern Minnesota that was developed in three phases, each phase having different installation dates and turbine models. I studied phase 3, which was completed in 1999 and comprises 138 turbines with a total capacity of 104 MW. The entire wind farm is laid out southeast-to-northwest along an elevated portion of the eastern edge of the Coteau des Prairies. Phase 3 is an extension onto the southeastern end of the project. The area is hilly and dry with few trees, and land use is a mix of row crops and grazing with a few small wildlife management areas with grasslands and wetlands. Turbines are clustered in strings of two to five each, arranged along the top of the ridge in a swath about 5 km wide. The smaller turbines are grouped more tightly, with only about 0.15 km spacing within strings. The fatality study was carried out by an environmental consultant, with searches conducted from spring through autumn of 1999. A full report to Northern States Power (Johnson et al. 2000) was made public and the results also were published in American Midland Naturalist (Johnson et al. 2003).

- Casselman Wind Farm is a 23 turbine, 34 MW facility in southwestern Pennsylvania operated by Iberdrola Renewables, and completed in 2007. The turbines are arranged along ridges in two main branches: one is along a deforested reclaimed coal mine site, and the other is along a forested ridgeline. The area is hilly and generally forested, with the Casselman River to the northeast. The closest turbine is within 1 km of the river. I collected data at the site in the autumn of 2011, in collaboration with Bat Conservation International, which had a team conducting fatality searches concurrently with acoustic recording for this study, which their team facilitated. This facility has been the subject of several BCI studies (e.g., Arnett et al. 2006, 2009, 2010) including searches in 2008 and 2009 as part of a study of the effectiveness of turbine curtailment as a mitigation strategy, and searches in 2010 to assess acoustic deterrents.

- Cedar Ridge is another facility in eastern Wisconsin, just south of Blue Sky Green Field, on the western edge of the Niagara Escarpment. This wind farm has 41 turbines and a capacity of 68 MW. It was completed in 2008 and is operated by Alliant Energy. The setting is similar to Blue Sky Green Field but is located about 12 km southeast of Lake Winnebago. Fatality searches were carried out by an environmental consultant during the spring and autumn of 2009 and 2010, the results of which were prepared for Wisconsin Power and Light and made public (BHE 2011).

- Fowler Ridge is a 600 MW capacity, 355-turbine wind facility operated by BP and Dominion Resources, completed in 2010. It is located in west-central Indiana, in a flat, agricultural setting. Turbines are dispersed throughout the farmland, but not in rows, at densities of one to seven turbines per 2.6 km^2 legal section. The project area is about 130 km total, and does not follow any topographic feature. A previous fatality study conducted by an environmental consultant from 2009-2011 (Good et al. 2012, 2013) resulted in the discovery of a federally endangered Indiana bat (*Myotis sodalis*) carcass, which prompted further research. I collected acoustic data as part of a collaborative effort with the U.S. Geological Survey and BCI. This study included night-vision video surveillance, mobile radar monitoring, and at-height acoustic recording in addition to fatality searches (Cryan et al. 2014).

- Penascal wind farm is a 168-turbine, 404 MW facility built in 2010, located in the southern tip of Texas, and operated by Iberdrola Renewables. The wind farm is set back about 6 km from the Intercoastal Waterway and about 12 km from the Gulf of Mexico. It is flat with

sandy soil and a mix of grasses, forbs, and shrubs, dotted with clusters of low-growing trees. The entire area is open range for cattle and game. The turbines are arranged in long strings running southwest-northeast. Strings are spaced about 2.5 km apart, and turbines are about every 0.25 km along a string. Fatality searches were carried out concurrently with acoustic recordings by personnel from Western Ecosystems Technology, who also maintained the recorders. Fatality data from this site were obtained via person communication with collaborators at BCI.

- Top of Iowa is a wind farm built in 2001 with 89 turbines and capacity of 80 MW, operated by Iberdrola Renewables. Its smaller turbines are arranged in a southeast-northwest strip of agricultural land 3 km wide and 8 km long. The northwest end of the farm borders two large wetland areas: Rice Lake State Park and Elm Creek Marsh State Wildlife Management Area. The wind farm was the subject of a MS thesis by Aaftab Jain (2005) at Iowa State University. Searches were conducted from spring to autumn in 2003 and 2004.

- Wolf Ridge wind farm is in northeastern Texas, just south of the Red River border with Oklahoma. The site is a grassy plateau with several forested ravines running north to the river plain. Turbines are situated both along the edge of the plateau as well as 1-2 km back from the edge. Most of the land is grazed by cattle. This facility has been the subject of a long-term fatality study by Texas Christian University (TCU). The students and post-doctoral assistants that carried out the fatality searches also maintained recorders for this study during three summer/autumn seasons. Fatality data for this site were obtained via personal communication with collaborators at TCU.

Data Adjustments

Acoustic data from four of the eight fatality study sites relied on collaborators operating the recorders. Whereas this allowed the geographic range of the study to expand dramatically, it also meant that the recording schedule at those sites coincided with collaborators' fatality search schedule. Most recent fatality studies, including the ones I collaborated with, conducted carcass searches only in late summer and autumn when most bat fatalities occur. They also generally conclude prior to the recording end date of my field season (November 15). As a result, recorder nights from these locations were clustered around a time of year that has higher bat activity than the whole-season average. Other sites included many recorder-nights in early spring and late

autumn, when pass rates are low, but these dates are missing for the four remote fatality sites. This sensitivity to seasonal variation in bat activity at fatality study sites meant that seasonally-adjusted means (described in General Methods: Adjustment for Seasonal Trend in Bat Data) were more appropriate for answering the research questions addressed in this project. The curve used to adjust data for this fatality study was generated using only data from the eight fatality study sites, rather than all sites, to create a baseline specific to this subset and to prevent seasonal patterns among high-activity sites in the Great Lakes (sites which were not included in analyses in this chapter) from influencing the shape of the curve.

Pass counts at these sites were heavily right-skewed. Most analyses here involved comparisons among means or groups of means, which were also right-skewed. Log-transformed means were approximately normally distributed and were more appropriate for the tests used in this analysis (Figure 9). In simple exploratory analyses and data summaries, unadjusted pass counts and means were used, but for formal tests and regression, log-transformed seasonally-adjusted means were used. For some analyses, results using unadjusted means are presented in addition to those using adjusted means to make interpretation of tests results and patterns more straightforward.

For this study some analyses used yearly mean pass rates (site-year mean), and some used means for the entire study period (site mean). Site-year means were used to examine whether recording over the course of one year (e.g., according to a developer or consultant's environmental impact assessment schedule) could provide a reliable description of activity levels at the site, or if multiple years are needed to differentiate among sites. Site means using the entire study period were used in comparisons with fatalities because this study focused on relating acoustic activity to fatality rates, which are single overall estimates per wind farm. Even if existing multiple-year studies provide yearly fatality rates, the application of this model (predicting fatality rates at future wind energy sites) would be independent of year.

In two instances, fatality counts by date were made available. For those locations, additional analyses were performed using nightly pass counts rather than site means. I looked at how pass counts and carcass findings varied within the fatality study period (Figure 14).

Tests

A preliminary analysis involving only the acoustic data was done to examine whether mean pass rates varied more between wind farms than within wind farms (i.e., among multiple recorder sites

within a single wind farm location). If that was the case, we would expect relatively consistent pass rates among recorders within a location, versus among recorders at different locations, and also among years at a single location. The ability to detect larger differences between wind farms than within wind farms would suggest that ground-level acoustic recording is a viable method of differentiating higher- and lower-activity locations, even given a large amount of random variation in pass rates (e.g., related to habitat characteristics near individual recorders or annual variation in activity). One-way ANOVA using site-year means (N=78) was a simple way to test for these differences between pairs of sites. Also, a more general analysis of differences between each pair of sites was done with adjusted means using Tukey's HSD (honest significant difference) test, which controls for the increased chance of finding significant differences when comparing multiple pairs of means. Finding that activity at recording sites was similar within locations but different between locations would provide evidence that pass rates are at least location-dependent, and not completely random.

The relationship between bat activity and bat fatalities was examined using simple linear regression of estimated fatality rate on seasonally-adjusted, log-transformed mean nightly pass rate. Generally, a single fatality estimate was available for each wind farm. If multiple fatality estimates were available from multiple studies or multi-year studies at a single site, they were averaged. In those cases, confidence intervals were provided for each estimate. Error for the average of the fatality estimates from a particular wind farm were calculated using the upper and lower margins of error provided, divided by the estimate to which it applied, giving proportional upper and lower margins for each estimate. These proportional margins were averaged across the multiple estimates, and then multiplied by the mean fatality rate for that wind farm to yield the upper and lower margins of error for the average fatality rate at that location. In other words, I took the average proportional error among estimates as the proportion of error for the average fatality estimate. The use of a single fatality estimate for each wind farm relates to the objective of this study, which is an examination of how acoustic pass rates relate to fatality rates. The application for this type of acoustic monitoring would be assessing prospective sites, which means finding the expected annual fatality rate prior to construction. In that context, each wind farm has a single true fatality rate, and adding data points to improve the chances of finding a relationship would not improve estimates of that rate.

Site means and site-year means in this data set were heavily right-skewed; however, log-transformed means were approximately normally distributed and more appropriate for the

regression analysis. If untransformed means were used, a concentration of means closer to zero would reduce the leverage among those points. Pass rate variance increased approximately in proportion to the square of the mean, and lower points have less variability, so a log transformation allows the smaller differences in the low end to contribute more to the regression fit. This was important given the small number of points (one per wind farm) used to model this relationship.

Where data were available, I replicated the main fatality regression of fatalities on pass rate with individual species, and used pass rates of species groups (e.g., migratory bats) as a predictor of total fatalities. Also, some studies provided data on the timing of fatalities. I used logistic regression to examine the probability of finding at least one fatality given pass rates at the site during nights prior to the find.

Results

Data collection at recording sites in Minnesota, Iowa, and Wisconsin was carried out according to the overall timeline schedule of the project, in the spring (March 15 – June 1) and autumn (August 1 – November 15). With collaborators in Texas, Pennsylvania, and Indiana, data collection generally occurred from mid-July or early August until the end of October, during the timeframe of fatality searches. Working with collaborators was a huge success, and data collection from remote sites was timely and occurred largely without interruption. One of the eight recorders at Penascal in southern Texas failed early in the recording season and could not be repaired or replaced by mid-season, and its data were excluded from all results and analyses. At Wolf Ridge wind farm in northern Texas, one recorder was relocated within the wind farm after being knocked down by cattle multiple times, and another was trampled beyond repair and had to be replaced mid-season. A total of 205,729 bat passes were recorded at 49 recording sites over the six field seasons (Table 5).

Table 5: Summary statistics for fatality study recording locations. Location means are mean nightly pass counts for all recording sites at the wind farm, over all years and seasons. Standard error of location mean is based on the number of recorder nights.

Wind Farm	Total Passes	Location Mean	Std. Dev.	Std. Error	2010 Mean Passes	2011 Mean Passes	2012 Mean Passes	Median Pass Count
Blue Sky	44273	38.70	78.03	2.31		38.10	39.32	8
Buffalo Ridge	2885	3.33	9.35	0.32		0.65	7.15	0

Casselman	6411	15.01	20.66	1.00		15.01		11
Cedar Ridge	15933	14.09	31.60	0.94		11.15	16.76	2
Fowler Ridge	19513	21.66	40.15	1.34			21.66	12
Penascal	31270	69.33	94.68	4.46		69.33		31
Top of Iowa	62508	54.12	119.38	3.51		40.81	71.43	11
Wolf Ridge	6672	6.53	11.41	0.36	2.59	11.94	4.92	3

All sites in the fatality study had low to medium activity levels relative to the range of pass rates observed in the project overall (including sites addressed in Chapters 2 and 3). Within this range, two sites had particularly low pass rates: Buffalo Ridge in southwestern Minnesota, and Wolf Ridge in northern Texas. The highest activity levels were recorded in southern Texas at Penascal and the other northern Iowa site, Top of Iowa.

Temporal variability in nightly pass counts was large, and standard deviations were nearly directly proportional to mean pass count. While year-to-year variation could be large for a single recorder, mean pass rates for a location (having three or more recorders) were fairly consistent among years, providing some evidence that pass rates described at least the general level of bat activity at each location.

Exploratory Analysis

Although the pass rates at these sites fit into the larger regional pattern discussed in the General Results and Landscape Chapter, geography does not explain much of the variation within this group. The best example of this is the difference in pass rates between Top of Iowa and Barton wind farm (Barton was a fatality study location that was ultimately omitted because fatality data were unavailable). These two wind farms are just across Interstate 35 from one another, with Top of Iowa located about 25 km west of Barton. They have similar ecological settings, but their pass rates differed by a factor of nine. The nearby water and trees of a state park and wildlife management area at Top of Iowa may explain some of this difference, but that effect would have to be much larger than those found in the landscape study (Chapter 2), which included analysis of similar features in a similar setting. Three out of four recorders at Top of Iowa had pass rates above 60, and two of those were more than 1.5 km from both state-owned properties. Viewing these two sites as replicates and using site years (mean pass count at one recorder in one year) as samples (n = 9 for Barton, n = 8 for Top of Iowa), ANOVA confirms a highly significant difference (p < 0.001).

Blue Sky and Cedar Ridge provide a less dramatic example of sites in close proximity with very different pass rates between, but not within, locations. These sites are about 20 km apart, and again using site-years as samples (n = 8 for each site) ANOVA suggests a significant difference in means (p = 0.047). Proximity to Lake Winnebago may explain why pass rates at Blue Sky are higher, but the lowest pass rate among all eight recording sites at the two locations was 6.7 passes per night at recorder Blue1, which is the closest site to Lake Winnebago.

I used a Tukey's HSD test to compare log-transformed, seasonally-adjusted mean pass rates for each site-year (Table 6). This test established whether the average pass rates in a given year could differentiate between locations, based on the consistency of pass counts observed among recorders within a location. In other words, if four recorders were set up at a wind farm and bats were monitored for one year, do mean pass rates tell us anything specific about that site, or would pass rates be similar no matter where monitoring took place? Results from the tests indicate that sometimes large differences between locations are apparent (Table 6). About half of the pairs are significantly different from each other. Several pairs have p-values near 1, but this is a consequence of a more stringent criterion for separating groups, and does not mean that sites are identical. One result of this stringency is that evidence of different means between Cedar Ridge and Blue Sky provided by the first ANOVA is not provided by the HSD test.

Table 6 P-values for Tukey's HSD Test of Log-Transformed, Seasonally Adjusted Mean Pass Rates. Values less than 0.05 are highlighted in green.

	Blue	Buffalo	Casselman	Cedar	Fowler	Penascal	Top
Buffalo	0.0000						
Casselman	0.6860	0.0141					
Cedar	0.3532	0.0537	0.9999				
Fowler	0.9977	0.0001	0.9508	0.6983			
Penascal	0.5443	0.0000	0.0108	0.0022	0.1056		
Top	0.6427	0.0000	0.0140	0.0027	0.1377	1.0000	
Wolf	0.0009	0.8309	0.2240	0.5443	0.0027	0.0000	0.0000

Regression of Fatalities on Pass Rates

I found no evidence of a significant linear relationship between pass rates and fatalities among the eight sites studied (Figure 12). Low pass rates were just as likely at high-fatality sites as low-fatality sites and vice-versa. Neither seasonally-adjusted, log-transformed means nor unadjusted

means were able to explain much of the variation in fatality levels, and simple linear regression lines were flat to slightly negative, the opposite of what was expected. Much of the same was true for regression with estimated pass rates for each migratory species, and all migratory species combined (Figure 13).

Where data were available, temporal relationships between fatalities and pass counts were examined (Figure 14). A logistic regression model of the occurrence of fatalities based on pass rates from prior nights did not provide evidence of a positive relationship between passes and fatalities. Fatalities at Fowler Ridge occurred mostly after acoustic activity rates had dropped off for the season. At Casselman, carcass findings and bat activity overlapped, but high pass rates during the night did not increase the probability of finding a fresh carcasses the following day.

Discussion

It may seem intuitive that both fatalities and acoustic activity would be dependent on the same variable: the number of bats using the airspace, but I found no evidence of that. Several factors, or combinations of them, may account for the lack of relationship, and include problems related to ground-level recording, inconsistent fatality estimators or unreliable fatality estimates, and differences between recorded bats and the bats that were killed.

Past studies have concluded that at-height recording (placing recorders above 30m on meteorological towers or turbines) provides better detection of bats that are at risk of collision or barotrauma fatalities (Kunz et al. 2007a). Both activity levels and species composition can be significantly different at-height than at ground level (Baerwald and Barclay 2009). The quick attenuation of ultrasonic-frequency vocalizations in air means that any bat recording device will be limited to sampling a very small portion of the total airspace. If bat activity patterns near the ground are different from those within heights of the rotor-swept zone (30 to 150 m above ground), then activity of at-risk bats may not be accurately measured by near-ground recorders. Although I chose to record at ground level in order to facilitate site selection and maximize the number of recorders in the field during a season, this may have resulted in an inability to measure the activity levels of at-risk bats.

At-height recording does not necessarily resolve the issue, however. Hein et al. (2013) used a similar analytical approach to synthesize results from 12 studies with both fatality searches and

acoustic surveys, including both ground level and at-height recordings, and found a positive but marginally significant (p = 0.07) relationship.

Inaccuracy of fatality estimates may also have contributed to the apparent lack of a relationship between acoustic activity and fatalities among wind farms. Wind-wildlife research is still a relatively new field, and methods for finding carcasses and estimating fatality rates are continually being improved. However, the fatality data used in this analysis span more than a decade, during which the assessment of wind farm impacts has rapidly developed. This progress has likely led to better estimates, but the changes have also made historical estimates less comparable to newer estimates. Further, the measurements (raw data) necessary to compute newer estimates often are not available in older studies.

Early studies improvised or used the best available methods (e.g., Jain estimated searcher efficiency and scavenger removal using house sparrow carcasses). Estimators used in earlier studies had been developed before patterns in carcass persistence and searcher efficacy were well understood (e.g. the naïve estimator, Johnson et al. 2003). Subsequent estimators (e.g., Schoenfeld estimator, Kerns and Kerlinger 2004) addressed these issues but regularly underestimated fatalities relative to later estimates (Huso 2011). Different fatality estimates based on the same search data can differ by a factor of three or more (A. Hale pers. comm. August 2013, C. Hein pers. comm. March 2012). Estimating fatality rates may be the most challenging aspect of wind-wildlife research, and the variability associated with the fatality rates used here may explain at least some of my findings of no relationships.

Conclusion

Ground-based acoustic surveys were able to detect differences in activity levels among wind farms, but pass rates were not found to be related to fatality estimates from prior or concurrent studies at those locations. Neither pass count mean nor seasonally-adjusted, log-transformed mean were good predictors of fatality rate. This is true for all species combined, as well as for each of the three migratory species, and all three migratory species combined. Differences in activity patterns between the low-elevation airspace sampled by acoustic detectors and the higher-elevation airspace of the rotor-swept zone may explain the lack of relationship.

Certain bats are more susceptible to fatalities at wind farms (hoary, silver-haired, eastern red, and perhaps Mexican free-tailed bats; Miller 2008, Piorkowski and O'Connell 2010), and fatality timing is heavily concentrated in the autumn. Although the causal mechanisms behind fatalities are not known, these two patterns establish that bat collisions are not random occurrences. Additionally, the airspace I sampled was not a random sample in either two or three dimensions. Apparently collisions and near-ground vocalizations either involve different groups of bats or result from different behavioral patterns. For example, if typical nightly movements involve numerous low-elevation traverses among roosts, water sources, and foraging areas, ground-based recorders will tally many passes. But if migratory movements later in the season are higher-elevation and involve more direct flights to reduce the physiological costs of long-distance movements (Fleming and Eby 2003), they would produce few, if any, pass files while also making the bat more likely to interact with a turbine. If that is the case, then the bats observed throughout the spring and summer may be an entirely different group of individuals than those discovered in fatality searches. Daily pass rates and fatality dates from Fowler Ridge (Figure 14, a) may be an example of this divergence.

Figure 11: Transformation of seasonally-adjusted nightly bat pass counts by natural logarithm. This graph includes only data from the eight fatality study sites. Formal regression analyses used transformed pass rates. Seasonally-adjusted data were used because many sites in this analysis had data collection seasons that did not overlap.
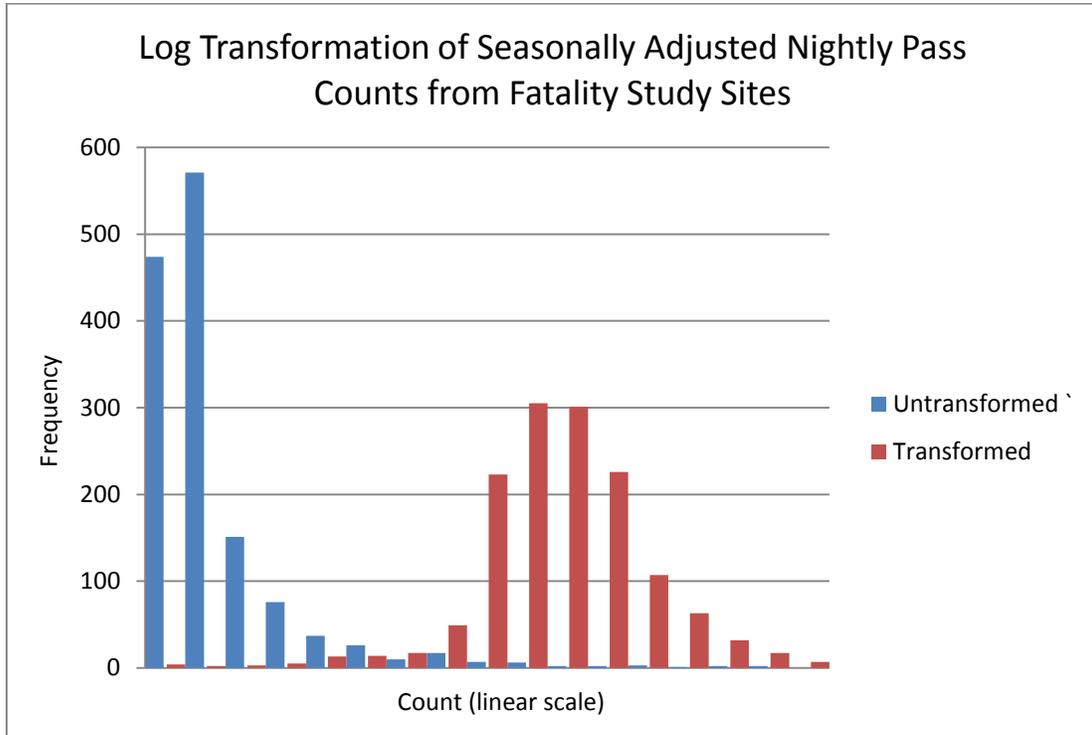
Figure 12: Regression of bat fatality rates on bat pass rates. Response is seasonally-adjusted log-transformed mean pass rate in (a) and mean pass rate in (b). Plot (b) is included to facilitate interpretation of the relationship. Neither plot indicates a strong linear relationship between fatalities and pass rates. Confidence intervals for fatality estimates were provided with the estimates as reported in literature or personal communication. Errors for pass rates were based on recorder-nights.

(a)

Bat Fatality Rate vs. Log-Transformed Seasonally Adjusted Pass Rate

$y = 0.086x + 16.784$
$R^2 \approx 0$

(b)

Bat Fatality Rate vs. Unadjusted Pass Rate

$y = -0.1665x + 21.638$
$R^2 = 0.1276$
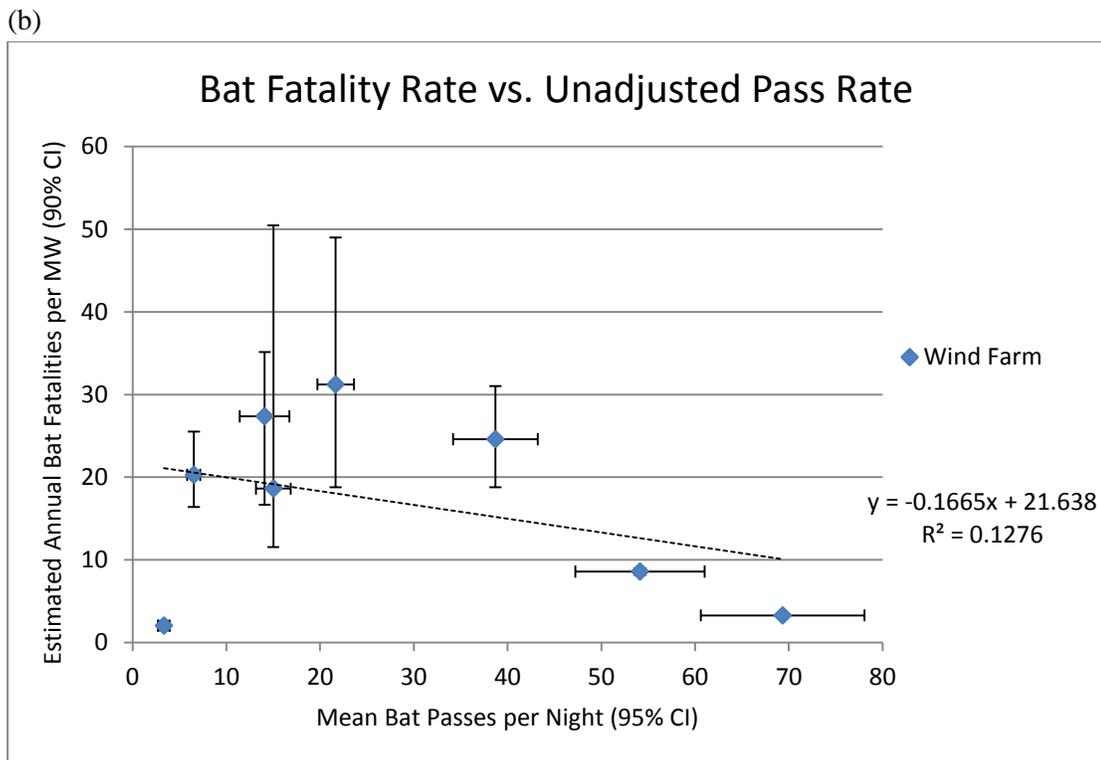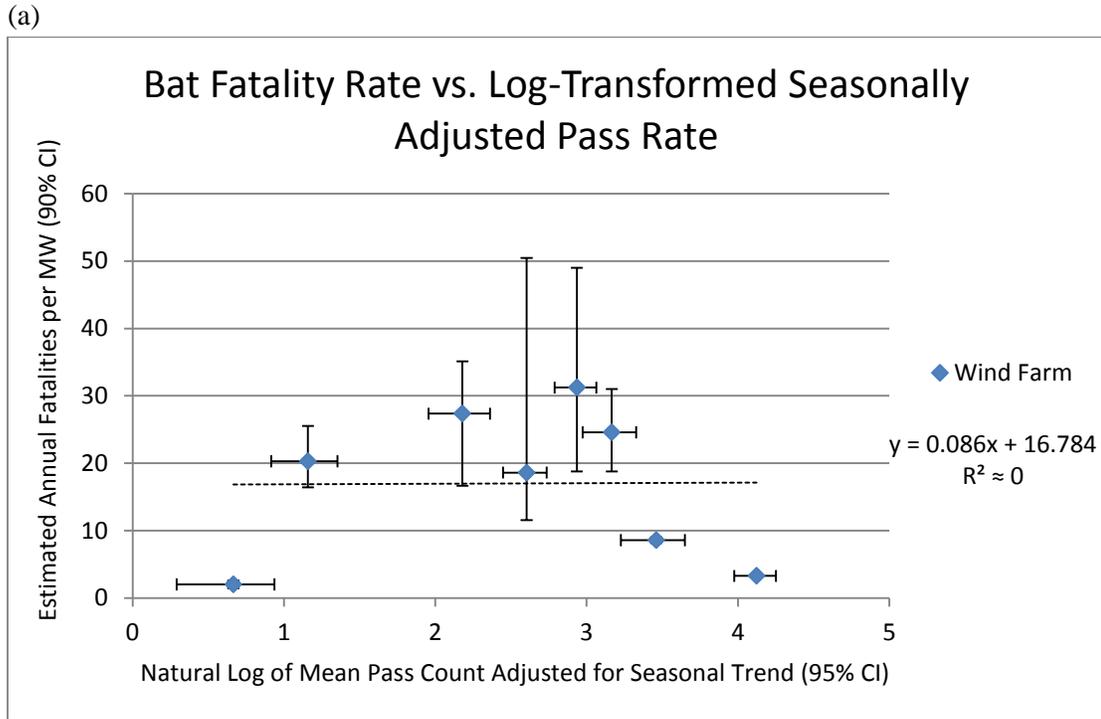
Figure 13: Fatality rate of all bats vs. pass rate for each migratory tree-roosting species (a, b, c) and all migratory species combined (d). The fatality rates of all bats were used because species-specific fatality rates were not available for some studies. No clear relationships were apparent in this analysis. LABO = eastern red bat (*Lasiurus borealis*), LACI = hoary bat (*L. cinereus*), LANO = silver-haired bat (*Lasionycteris noctivagans*)

(a)

(b)

(c)

(d)
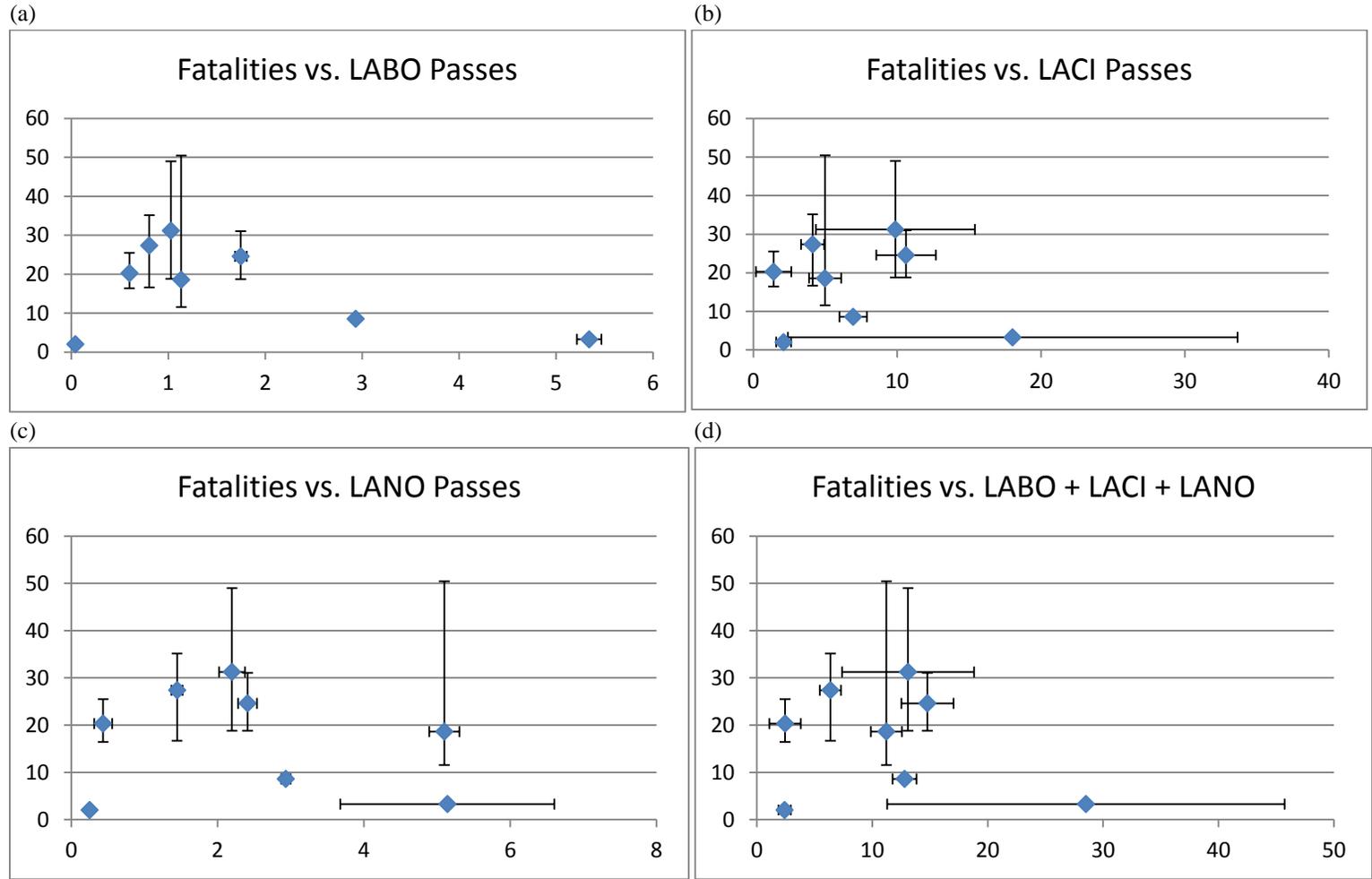
Figure 14: Pass counts and fatality findings by date at Fowler Ridge and Casselman wind farms. Three-night moving average of pass counts for recorder arrays (listed by turbine ID) and fatality findings at Fowler Ridge (a) and nightly pass count (listed by recorder ID) with fresh (night prior) fatality findings at Casselman. Three-night average is used for Fowler since fatality data for that site included all found carcasses. Carcasses have a decreasing probability of being found over time, so activity on the three nights prior to finding a carcass was assumed to be a better predictor of fatalities. Fatality data were provided by Bat Conservation International (C. Hein pers. comm. November 2013 and M. Schirmacher, pers. comm. May 2014)

(a)

(b)

Casselman Pass Counts and Fatalities from Prior Night
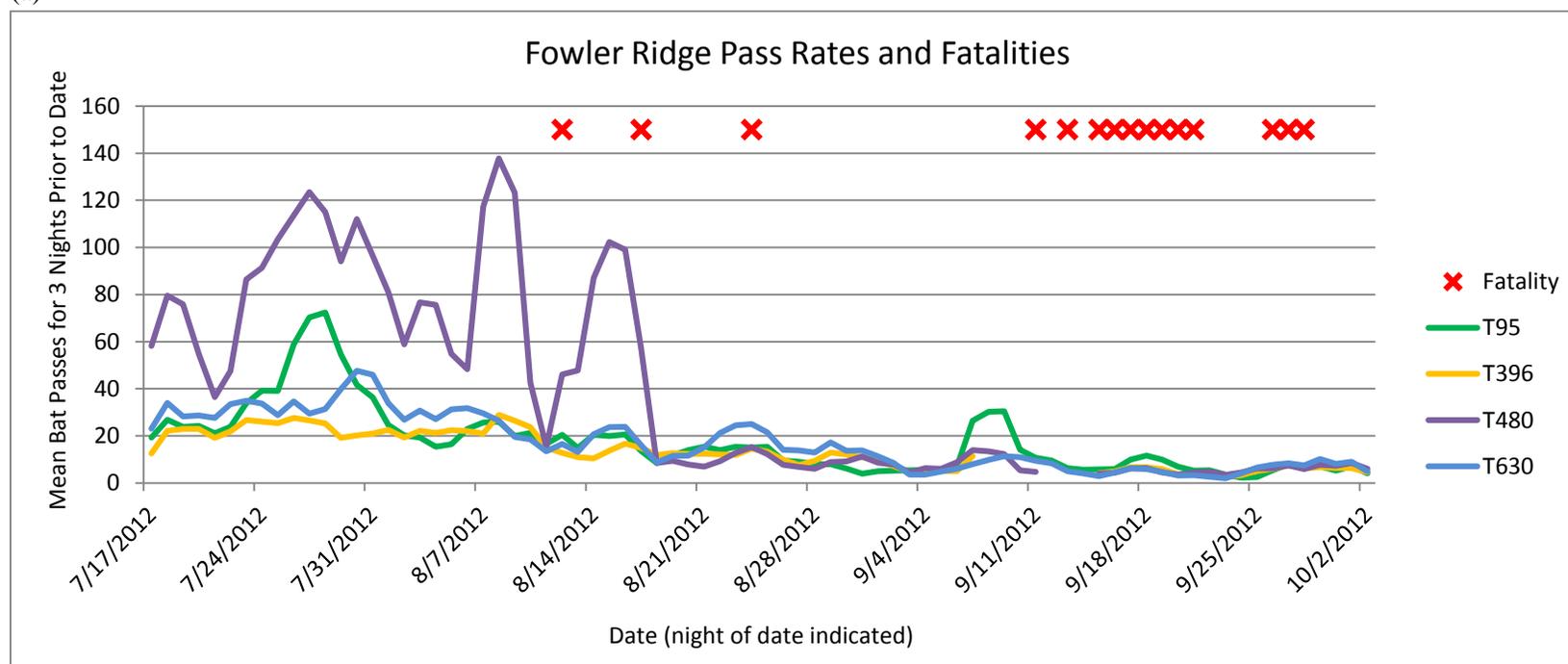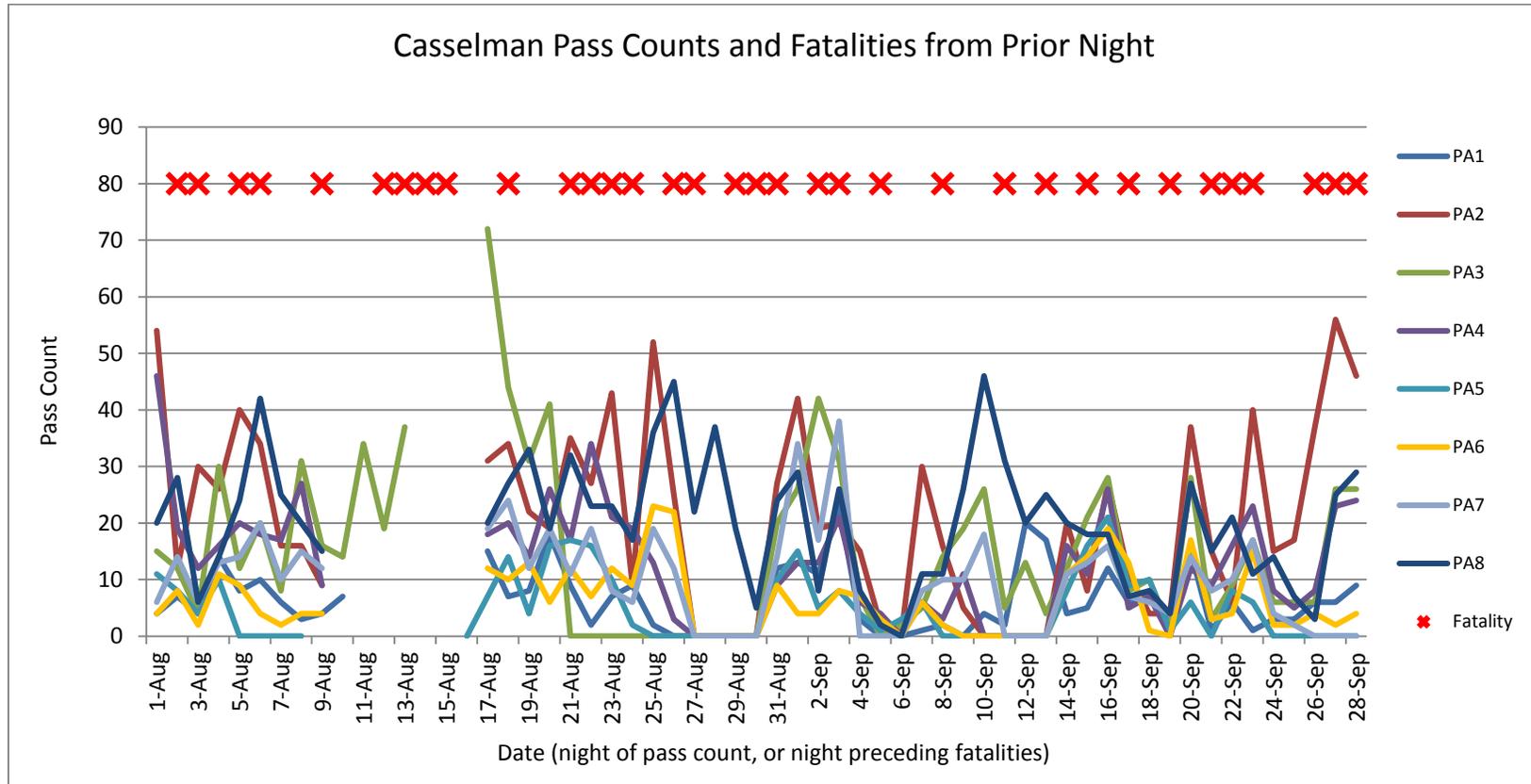
Chapter 2: Effects of Landscape Features on Bat and Bird Pass Rates

Introduction

The focus of this study was understanding how spatial distributions of birds and bats during migration seasons relate to particular landscape features. Studies of fatality rates of bats from over a decade of wind wildlife research are beginning to uncover some broad geographic patterns (Arnett and Baerwald 2013), but we still know very little about how habitat and landscape features affect either flying migrant activity or fatalities. Migratory movements may be a critical factor in determining the spatial distribution of wind turbine impacts. Movement corridors and areas of migrant concentration of some birds have been relatively well documented (Faaborg et al. 2012), but little is known about migration routes for migrating bats (Krauel and McCracken 2013). New technologies are providing ever more detailed views of migration, from exact tracks of individuals large enough to carry a satellite transmitter (NEC 2014) to continental views of mass movements on weather radar (Bonter et al. 2009). Acoustic monitoring may be an additional tool for learning about the movement patterns of birds and bats, both in relation to prominent landscape features and at larger geographic scales.

Movement corridors can be defined in many ways, but basically a corridor is an area or volume (Kunz et al. 2008, Diehl 2013) with elevated numbers of animals moving through it, relative to other areas outside the corridor. To identify corridors, we can measure and compare passage rates within areas with differing habitat and landscape settings, and across wide geographic regions. To explain why traffic is higher in some areas than others, we can study local and regional features that might influence migratory patterns.

Understanding bat migration routes and behaviors is likely to be critical to understanding patterns in bat fatalities (Cryan and Barclay 2009); however most research on aerial migration to date has focused on birds. Ornithologists have long recognized that migrating birds congregate on peninsulas and along shorelines of oceans, rivers, and large lakes during migration (e.g., Gauthreaux 1971). Large bodies of water may constitute movement barriers to migrants

(Goodrich and Smith 2008), serve as navigational guides (Alerstam and Petterson 1977), or simply provide food and roosts for birds moving through agricultural landscapes (Ewert and Hamas 1996, Buler et al. 2007). In the Great Lakes region, large movements of birds along coastlines have been observed for decades (e.g., Tyrell 1934). More recently, Doppler weather radar has been used to examine the widespread use of Great Lakes coasts by migrating birds (Diehl et al. 2003, Bonter et al. 2009), and Bardon (2012) and Peterson (2013) have documented mass movements of passerines along Lake Superior.

Our knowledge of the life history of bats is lacking for many species, but we do know that many bats migrate long distances (Cryan et al. 2004). In the Upper Midwest, the three long-distance migrants (hoary, eastern red, and silver-haired bats) are common summer residents. Additionally, some species including the federally Endangered Indiana bat (*Myotis sodalis*) and one species currently proposed for Endangered status, the northern long-eared bat (*M. septentrionalis*) migrate regionally between summer and winter habitat. While making long-distance or regional movements, bats may be subject to constraints similar to those faced by migrating passerines, such as limited flight range and the need to refuel (McGuire et al. 2012). If Great Lakes coastlines affect the migratory routes of bats the same way they affect birds (i.e., by impeding, guiding, or providing stopover resources), it is possible that large numbers of bats move through near-coastal areas in the Great Lakes region during migration seasons, and would be affected by land use, such as wind energy, along those coasts.

Bat fatality rates at wind facilities in the Midwest have been relatively high (Arnett and Baerwald 2013), and while long-distance migrants may be most vulnerable, resident and short-distance migratory bats also suffer fatalities. These include species of highest conservation concern and species already experiencing population declines. Recent mortality associated with the fungus *Pseudogymnoascus destructans*, commonly known as white-nose syndrome (USFWS 2012), has been devastating hibernating bat colonies across the eastern and midwestern U.S. over the last seven years and heightens the need for conservation of these populations.

Some of the analyses in this study of landscape effects group all species of bats together and all analyses group all species of birds together. While migration patterns vary by bird species, and are likely to vary by migratory bat species, there is little evidence that bird fatalities vary by species (Loss et al. 2013). Bat fatalities are a different case, and the three species found most frequently by fatality searches (hoary bat, eastern red bat, and silver-haired bat) are combined into

a separate group whenever possible. Mexican free-tailed bats (*Tadarida brasiliensis*) also are suspected to be in this more vulnerable group, but the geographical distribution of study sites, being mostly in the northern U.S., did not allow me to record and manually identify enough passes to have confidence in the numbers of this species reported by the automated identification process to include in species-specific analyses.

I studied bat and bird pass rates with acoustic monitors at multiple geographic scales to examine whether certain areas had elevated activity levels during migration seasons, and what landscape factors might influence those levels. As such, findings of this study may be applicable to wind energy development for macro-siting (deciding the general area in which a wind farm should be built) as well as micro-siting (determining project boundaries and individual turbine placement).

Specifically, I conducted three analyses focused on spatial variation in bat and bird pass rates. In the first analysis, arrays of recorders were set up at pre-specified distances from landscape features (distance arrays) to examine how pass rates varied with distance from the edge of those features. The other two analyses were carried out with data from all recorders (including those addressing objectives in Chapters 1 and 3), using their locations within geographic regions and the distance to features such as trees and water to study pass rate variation with respect to those attributes.

The three analyses in this chapter:

1. Distance Arrays examining local-scale effects of three specific types of landscape features on pass rates
   a. Forested river corridors in mostly agricultural settings in the Upper Midwest
   b. Grassland patches in mostly agricultural settings in the Upper Midwest
   c. Great Lakes coastline along Lake Michigan
2. Regional comparisons of Great Lakes coasts to inland sites (all recorders)
   a. Broad scale comparison of Great Lakes sites to inland sites
   b. Finer-scale analysis involving sixteen Lake Michigan coastal sites and eight recording sites located 45 km inland from Lake Michigan
3. General analysis of local and regional effects (all recorders)
   a. Model of pass rates based on local landscape attributes such as distance to trees and water

Methods

Local Effects of Landscape Features at Distance Arrays

Forested river corridors, grassland preserves, and Great Lakes coastlines were selected as landscape features of interest for their potential effects on bat and bird movement during migration seasons. Within the setting of mostly agricultural land used in the Upper Midwest, these features were seen as possible migration corridors or stopover areas. Additionally, multiple features of each type were available to be studied within the geographic scope of this project. Forested river corridors running predominantly north-south in southern Minnesota were well situated to anchor recorder arrays extending east or west from the forested edge into farmland, facilitating observations of the differences in movement (migratory or otherwise) at various distances from the edge. Relatively large grassland preserves in southwestern Minnesota provided the same opportunity to study differences across an east-west gradient. Collaboration with the U.S. Fish and Wildlife Service provided access to Great Lakes shorelines, where data was collected from east-west distance arrays beginning at the western shore of Lake Michigan.

Study Sites – Distance Arrays

Forested River Corridors

Recorders within distance arrays at forested river corridors and were 50, 500, 1500, and 5000 meters from the edge in 2010. In subsequent years, after finding evidence of elevated activity levels at 50m but not at other distances at forested river corridors, a recorder was added at 200 m, to observe the gradient of activity with distance at a finer scale.

- Martin County forested river corridor array was set up on the east side of the East Chain River in south-central Minnesota. The recorders extended from the forest edge east along a fence line to the middle of a farmed section at 500 m, and then out to two drainage ditches at 1500 m and 5000 m.

- Jackson County forested river corridor array was similar to Martin County, extending east from the eastern edge of the Upper West Branch des Moines River corridor, through agricultural fields and ending at the shoulder of a drainage ditch at 5000 m. The "edge" of the Jackson County array was difficult to define, as the river bends from south to southwest

near the array. Each recorder was placed at least the specified distance away from the nearest forest edge.

- Rockville County Park was a forest array stretching north from the Sauk River corridor in central Minnesota. After an effect of proximity to edge was detected from bat calls in the 2010 and 2011 recording data from Martin and Jackson County arrays, the Rockville Park array was added in 2012 to try to replicate those findings.

Grasslands

Recorders within distance arrays at forested river corridors and were 50, 500, 1500, and 5000 meters from the edge in 2010. In subsequent years, after finding evidence of elevated activity levels at 50 m but not at other distances at forested river corridors, a recorder was added at 200 m, to observe the gradient of activity over distance at a finer scale.

- Blue Mounds was a grassland array extending west from the western edge of Blue Mounds State Park in southwest Minnesota, into a mix of cropland and pastures. Like the Jackson County array, the edge of the grassland was difficult to define due to the irregular shape of the State Park.

- Tall Grass was a grassland array near Blue Mounds, extending west from the edge of a large portion of the Northern Tallgrass Prairie National Wildlife Refuge, into a mixture of cropland and pasture.

Coast of Lake Michigan

I assumed that a large ecological barrier such as Lake Michigan would have a much farther-reaching effect on pass rates than small river corridors or grasslands in central Minnesota, which meant that wider distance arrays would be appropriate. Additionally, data collection for these arrays was carried out by USFWS collaborators who were also using mobile radar units to study migratory movements in the area. In order to collocate with the USFWS radar stations, Great Lakes arrays were placed within 500 m, 5 km, 10 km, and 16 km of the western shoreline of Lake Michigan. The three arrays span a 115 km stretch of the central Lake Michigan coastline in Wisconsin, beginning just south of the Door Peninsula.

- Kewaunee was the northernmost Lake Michigan array, positioned north of the Point Beach array, near the base of the Door Peninsula.

- Point Beach was a Great Lakes coastal array north of Belgium and about 25 km south of Kewaunee. It extended west from the western shore of Lake Michigan, beginning near the town of Two Rivers, WI.

- Belgium was the southernmost Great Lakes coastal array, about 90 km south of Point Beach. It extended west from the western shore of Lake Michigan near Port Washington, WI.

Great Lakes recording sites included a mix of public and private lands, and some sites (e.g., Belgium 10 km and Kewaunee 500 m) were in urban settings. Forested river corridor and grassland arrays had 50m sites on public or private lands, and all other distances (200 m, 500 m, 1500 m, and 5000 m) on private farmland.

Analysis - Distance Arrays

Exploratory Analysis
One objective of this research was to examine whether the acoustic recorders were capable of simply detecting differences in bird and bat activity levels between sites. Examining whether mean pass rates differed significantly among recorders within distance arrays was one way of addressing this objective, and also provided information on the distances across which differences could be detected. Arrays of a particular type (forested river corridor, grassland, or Great Lakes coast) were considered replicates. Differences between pass rates within each array were compared using ANOVA, but since up to five groups were being compared within each array, Tukey's HSD tests were used to correct for the increased probability of Type I errors from multiple comparisons. Results of these tests indicated differences in mean pass rates between recording sites within arrays, and the direction of these differences (positive or negative).

Modeling
Mixed effects models were used to examine the effect of distance from the edge while controlling for the effect of location (e.g., Martin County array). Predictors of log-transformed nightly pass count included both distance and the reciprocal of distance (since activity might be expected to drop off in a non-linear fashion with increasing distance from an area of concentration) as fixed effects and location (array) as a random effect.

Regional Comparisons of Great Lakes Coasts to Inland Sites

In addition to the three Great Lakes coastal arrays, collaborators at the USFWS placed recorders at 59 other sites along the coasts of Lake Michigan, Lake Huron, Lake Erie, and Lake Ontario (Figure 2). One important concern I hoped to address with this project was the prospect of wind farm development in near-coast areas of the Great Lakes region. Comparing activity levels at Great Lakes coasts to a range of inland locations from southwestern Pennsylvania to southwestern Minnesota and Texas was one way to assess whether migratory activity might be concentrated near Great Lakes at the continental scale.

Large differences in pass rates among geographic regions (e.g., southwestern Minnesota, Lake Michigan Coast) emerged early in data collection for this project. In particular, some Great Lakes coastal sites (sites within 16km of the shoreline) had exceptionally high nightly pass rates, and overall activity in this region was elevated relatively consistently among recording sites (Figure 21).

Study Sites – Great Lakes Comparison

To include the widest possible geographic range of sites for the comparison of Great Lakes coastal sites to inland sites, all recording locations, including those associated with other primary objectives (see Figure 2) were included in the analysis. For the comparison of coastal sites (within 16 km of a lakeshore) to nearby inland sites (45 km inland), sixteen recording sites along the mid-latitude portion of the western Lake Michigan shoreline were compared to eight recorders dispersed throughout two inland wind farms just west of the coastal sites (Figure 17).

While certain areas of southern Minnesota, and some shorelines of Lake Michigan, Huron, and Erie were relatively well sampled for ground-based acoustic activity, many regions included in this analysis were not. Data collected outside the core area of the study (e.g., Pennsylvania, Indiana, and Texas) helped develop a frame of reference for the range of possible observable pass rates, but should not be seen as representative of bat activity in those regions.

Analysis – Great Lakes Comparison

To test for the difference in activity levels between Great Lakes coastal sites (within 16 km) and all other inland sites, an ANOVA of log-transformed mean pass rates was used to compare Great Lakes coastal recording sites to all other inland recording sites. Since log-transformed mean pass

rates are only approximately normally distributed, a Kolmogorov-Smirnov (K-S) non-parametric test was used to confirm the difference in distributions of pass rates among Great Lakes and inland sites. The same tests were used to examine the difference in mean pass rates between a cluster of study sites 45km inland from Lake Michigan and coastal sites within 16km of Lake Michigan.

General Analyses of Local and Region Effects

Recording sites in the distance arrays were sited specifically to examine how bat and bird activity vary at pre-specified distances from select features. However, all recorders can be used to evaluate effects of landscape characteristics in a more general analysis. The spatial relation of each recorder to surrounding habitat features can be used to examine how these features relate to pass rates.

Local Model

Distance from trees, distance from water, and EPA Ecoregion were used as predictors of seasonally-adjusted, log-transformed mean pass rates. Distance to water and trees might be expected to have a non-linear response (i.e., effect decreases with distance), so the inverse (reciprocal) of both of these distances were also included as predictors.

Distances were measured manually from satellite imagery. I initially attempted to use automated methods to measure these distances using National Wetland Inventory and National Land Cover Database datasets, but values assigned to recorders from these datasets were not consistent with my first-hand knowledge of the field sites. For example, many dry sites in southwestern Minnesota are close to ephemeral drainage courses through farm fields. Sites like this were assigned a short distance to water when calculated by a GIS, however the sites are far from any water source useable by bats during most of the study period. For the purposes of this analysis, water sources relevant to bats need to be available on a consistent basis in the spring and autumn, and be large enough for a bat to drink from, which excludes some features such as heavily vegetated drainage ditches. "Trees" were defined as edges of forested areas, or stands of three or more large trees, including homestead and farmland windbreaks. Some bats may prefer to roost in trees that are in groups, rather than isolated trees (Kunz and Lumsden 2003). Ecoregion was used as a broad generalization of habitat type that may contribute to patterns in bird or bat abundance and therefore activity. Both Level 3 (broader) and Level 4 (more specific subdivisions of level 3 regions) were used as categorical predictors.

Models containing all possible combinations of the predictors, excluding directly related pairs of variables (distance to trees and inverse distance to trees, distance to water and inverse distance to water, Ecoregion Level 3 and Ecoregion Level 4), were formulated and evaluated. The Akaike information criterion (AIC) was used to rank models according to a combination of fit (likelihood that the model is correct, given the observations) and simplicity (fewer terms).

Regional Model

Bat and bird pass rates are likely influenced by factors at both the local and regional scales. To understand regional differences in activity and generalize about activity levels within a region, local effects must be controlled for. A linear mixed effects model with region as the fixed effect and local factors such as distance to trees and water, and habitat (as generalized by Ecoregion) was fitted to examine the true differences in pass rates among regions. The response variable was log-transformed nightly pass count. The fixed effect of region was a ten-level factor, referred to as "10Region" in Appendix A, containing the regions: Minnesota central, Minnesota southern (including northern Iowa), Minnesota southwestern, Lake Michigan, Lake Huron, Lake Erie, Eastern Wisconsin, Upper Peninsula of Michigan, Eastern (including Pennsylvania and Indiana), and Texas. The set of local variables to be used as random effects was determined by results of the Local Model comparison (described above), excluding Ecoregions, which correspond closely to the recorder regions used.

Results

I found strong evidence that forest edges are areas of elevated activity for both bats and birds, and that this activity drops off quickly with distance from the edge. I also found that distance from water, distance from trees, and Level 4 Ecoregion can be useful predictors of bat activity, whereas bird activity varied more by the broad classification of Level 3 Ecoregion than by the other predictors.

Local Effects of Landscape Features at Distance Arrays

Exploratory Analysis – Distance Arrays

Bats

As seen in Figure 15, a strong pattern of elevated activity at recorders near the edge of forested river corridors was detected at all three landscape arrays: Jackson County, Martin County, and Rockville Park. Pass rates decreased systematically at all four distances, except for Rockville 1500 m. The Rockville Park site was a fence line that extended north from a forested corridor, but approached an upland woodlot at its far end, near the 1500 m recorder. For this reason I deployed no recorder at 5000 m. This situation allowed me to examine the effect of forest edge at both ends of the array, without the effect of water at the 1500 m end. Pass rates suggest that activity began to rise again approaching the upland area and that trees in the absence of water may still affect activity.

Bat activity at the grassland arrays was much lower (note the y-axes in Figure 15), and did not show a similar pattern. Heightened activity at the 1500m site for both Blue Mounds and Tall Grass may be some type of response to the landscape, but were relatively small in magnitude (pass rates at these sites were generally very low) and not thought to be biologically significant. Data from these sites did not indicate that grasslands have a similar effect on activity as forest edges.

The Lake Michigan distance array sites had widely varying pass rates, both within and among arrays. No systematic pattern of concentrated bat activity near the coast was apparent from these sites, which may have been heavily influenced by local habitat conditions (discussed in the next section) rather than distance from shore.

The Tukey's HSD tests (Table 7) confirmed the differences apparent in the Figure 15. Elevated activity levels near forested river corridor edges were found to be significant. Forested river corridor edge locations had higher activity than all other distances (there is no 5000 m site at the Rockville Park array). This finding was consistent across all arrays of that type, which include two in southern Minnesota (Martin and Jackson) and one in central Minnesota (Rockville). At grassland arrays in southwestern Minnesota the HSD tests confirmed an unexplained rise at 1500 m at both arrays. Result from the Lake Michigan arrays are mixed, and do not provide much

support for the hypothesis of elevated activity closer to the coast, at least within the arrays used in this study.

Bats by Species

Among the distance array sites, spikes in overall pass rates (Figure 15) consist of elevated activity for multiple species (Figure 16), meaning there is some correlation between activity levels of different species. And in fact, the average correlation between each pair of species among all distance arrays is 0.80, with especially high correlation among smaller, high-frequency bats (average r = 0.91 for little brown, MYLU; northern long-eared, MYSE; evening, NYHU; and tricolored bats, PESU).

Two species are particularly common, hoary bats (LACI) and little brown bats. The relative abundance of these species appears to depend on geography, with little brown bats more prevalent near Lake Michigan, hoary bats more prevalent in southwestern Minnesota, and an even mix in central and southern Minnesota.

Among migratory tree-roosting species, hoary bats are the most prevalent in all three regions. The activity level pattern of hoary bats represents a fairly good approximation of the general pattern of all bats at the landscape arrays. It also is a relatively accurate reflection of activity among the three migratory species (r = 0.73).

Birds

Bird activity at landscape arrays was somewhat similar to bats, but the main feature of bird activity was intense variation in both nightly pass rates and mean pass rates among sites (Figure 18). This included very low pass rates at many sites. Decreasing activity with distance is apparent at the forested corridor (as well as the rebound at Rockville 1500 m), but the pattern was not as clear with birds as with bats, especially with low pass counts at the Jackson edge site. Pass rates at these arrays appear to be much more dependent on site than distance from edge.

Some evidence of elevated bird activity at grasslands was found at the edge location of the Tallgrass NWR array, but the result was not similar at nearby Blue Mounds array. Aside from the peak in pass counts at the Tallgrass edge, activity levels did not appear to follow any pattern.

As with bat activity, bird passes at the Lake Michigan arrays were highly variable. Pass rates do not appear to increase or decrease systematically by distance at Point Beach or Belgium, but there

does appear to be a consistent drop-off with distance at the Kewaunee array. Much of the variation in pass rates may be attributable to local landscape or habitat features, and the pattern observed at Kewaunee was not replicated in the other two arrays.

The Tukey's HSD tests (Table 7) indicated significant differences between edge and all other distances at 2 out of 3 forested corridor arrays. This finding may provide evidence of higher bird activity near forested river corridor edges within an agricultural setting, but the result is not as conclusive for birds as it was for bats. Results from the other two arrays at grasslands and Lake Michigan were more varied and with the possible exception of the Kewaunee array, they do not suggest nor confirm any particular activity pattern with regard to distance from the landscape features selected for this study.

Modeling Local Effects at Distance Arrays

Models of the relationship between bat and bird activity and proximity to the edge of forested river corridors used combinations of distance, inverse distance, and site with varying degrees of success. The main difference between bat activity and bird activity was that bat activity was relatively consistent among arrays, while bird activity levels varied markedly by array.

Bats

At forested river corridor arrays, where a pattern of elevated activity near the edge is apparent from mean pass counts (Figure 13), inverse distance from the edge was the best predictor of log-transformed pass rates in a linear mixed effects model with location included as a random effect. Inverse distance was highly significant ($p < 0.001$), with a coefficient of 1.32. This model was a better fit than a similar model with distance as the fixed effect (difference in AIC of 294). Both mixed effects models performed far better than simple linear models with distance and location, or just location as the predictor.

At Grasslands, neither distance nor inverse distance were particularly useful predictors of pass rates, as models containing only a term for the effect of location (array) fit the data no better than models with location and distance terms. Reductions in AIC for mixed models with distance and inverse distance, compared to the location-only model, were only 3 and 17, respectively.

At the Great Lakes Arrays, the effect of distance was significant, but with a small positive coefficient, suggesting slightly increasing pass rates with distance. Models with location as the only term performed about the same as models with location and distance terms.

Birds

At the forested river corridors, distance terms were found to be useful as predictors of pass rates, but to a lesser extent than they were for bats. Inverse distance was found to be a better predictor than distance, with models including distance and inverse distance having AIC of 3 and 141 less than a model with only a location term, respectively.

Distance was not a significant predictor of bird pass rates at grassland sites. AIC scores of models with and without distance and inverse distance terms were within 50 of one another, and the model with location as the only predictor performed slightly better than the model including distance and slightly worse than the model including inverse distance.

Similarly at Great Lakes distance arrays, distance was not a useful predictor of bird pass rates, with a small positive and insignificant coefficient. AIC scores were all within 20 points of one another, with the location-only model again ranking in between the distance and inverse distance mixed models.

Regional Comparisons of Great Lakes Coasts to Inland Sites

The first comparison was a broad-scale analysis of pass rates among two groups of recorders: 1) those within 16km of Great Lakes coastlines and 2) those further inland in Minnesota, Iowa, Wisconsin, Pennsylvania, Indiana, and Texas. Huge differences in both bat and bird pass rates between Great Lakes coasts and inland sites were detected (Figure 21). Out of the 15 regions used in this analysis, the six Great Lakes regions had the highest pass rates, both for bats and birds. The difference between Great Lakes pass rates and other regions was highly significant in an ANOVA with log-transformed mean pass rates ($p < 0.001$) as well as a Kolmogorov-Smirnov non-parametric test with untransformed means ($p < 0.001$).

The second comparison involved eight recorders at wind farms in eastern Wisconsin, just 45 km inland from the Lake Michigan coast, which were compared to sixteen recorders within 16km of the Lake Michigan shoreline, at approximately the same latitude (Figure 22). The eight inland recorders had both bat and bird activity levels significantly lower than the sixteen coastal locations (ANOVA $p = 0.034$, K-S $p = 0.039$ for bats, and ANOVA $p < 0.001$, K-S $p < 0.001$ for birds). Activity levels at the eight inland sites in eastern Wisconsin were more similar to distant locations in central Minnesota and Iowa than the nearby coastal sites.

General Analyses of Local and Regional Effects

Local Model

To model the effect of particular landscape characteristics surrounding recorders on activity, multiple models with combinations of potential covariates were formulated and compared. Distance to trees, inverse distance to trees, distance to water, inverse distance to water, and Ecoregion (EPA Levels 3 and 4) were tested as predictors of log-transformed bat and bird pass rates. All recorders, including those with alternate primary objectives (Chapters 1 and 3) were included in this analysis. Model selection consisted of ranking all models by AIC.

This process resulted in a fairly useful model for bats, which included distance to water, inverse distance to trees, and Level 4 Ecoregion as predictors and had an adjusted R^2 of 0.662. The result for birds was less meaningful, with and adjusted R^2 of 0.362 for the top model, which included only Level 3 Ecoregion, the broadest geographical predictor. Full descriptions of candidate models and AIC rankings are in Tables 9 and 10.

Distance to water was a highly significant predictor of bat pass rates ($p < 0.001$), whereas inverse distance to trees was also significant ($p = 0.022$) (Table 9). Three Ecoregions were associated with elevated bat pass rates: Door Peninsula (two recorders) and Erie/Ontario Lake Plain (eight recorders) had positive effects and Loess Prairies (sixteen recorders) had negative effects. The term for the Menominee-Drummond Lakeshore Ecoregion (eight recorders) had a p value of 0.056, with a positive effect. The top bird model (Table 10) had Level 3 Ecoregion as the only predictor. Loess Prairies, Des Moines Lobe, and Grand Prairie were all significant factors with negative effects on pass rates.

Regional Model

To examine the importance of region in determining bat pass rates, a linear mixed effects model was formulated, with the best local-scale predictors included as random effects, and region included as the only fixed effect. Results from the Local Model comparison above were used to identify the local-scale predictors. Water and inverse distance to trees was the best pair of local predictors in model comparisons both including and excluding models with Ecoregion as a potential covariate. Ecoregion was excluded from the regional model since it corresponds closely

to region as defined in this study. As in the previous analysis, the response variable was the log-transformed mean nightly pass count of each recording site.

The model including region was a much better fit than the model with only local-scale predictors. The AIC difference between the two was 104, and the likelihood ratio p value was less than 0.001. Four regions were identified as significant factors with either positive or negative coefficients: Lake Erie ($+ 2.11$, $p < 0.001$), Lake Michigan ($+1.52$, $p < 0.001$), southwestern Minnesota (-2.25, $p < 0.001$), and Upper Peninsula of Michigan ($+3.68$, $p = 0.002$). Coefficients relate to the estimated increase or decrease in the natural logarithm of mean pass count for sites in that region above or below the overall mean pass count of all sites, after controlling for the effects of distance to trees and water. In other words, a recorder in the Upper Peninsula would be expected to collect about 40 passes per night more than a recorder at an average site, given identical setting with respect to the nearest trees and water.

Discussion

Results of landscape analyses for bats and birds differed, as expected, but some clear patterns were evident across taxa. Both bat activity and bird activity appear to vary by geographic region at a very coarse scale. Drier grassland sites in southwestern Minnesota had the lowest levels of bat activity and relatively low levels of bird activity. Sites in central and southeastern Minnesota and eastern Wisconsin had moderate activity of both taxa, and Great Lakes coastal sites had the highest pass rates for both bats and birds. At a local scale, activity for both groups was consistently concentrated near forested edges.

Generally, differences in bat activity seemed to be more easily detected at the local scale. Distance array analysis and landscape modeling both indicated that local patterns can be detected by ground-based monitors. Bird activity varied locally, but not in predictable ways, and the only apparent consistency was at the regional scale. This difference between bats and birds is surprising, especially given the difference in reception range for acoustic and ultrasonic signals. Bird microphones captured a much larger volume (i.e., 10 times the reception radius results in about 500 times the recording volume if reception is hemispheric) of the airspace, but many sites had very low pass rates and variations in pass rates didn't seem to average out over many nights of recording. Bat pass counts varied as well, but seemed to have some level of consistency, and at many sites local patterns could be discerned after just one year of monitoring.

The disparity between local-scale detection of patterns in pass rates for bats and birds was evident in the modeling results as well. Models with local variables worked better for bats, but the model with only the coarsest variable (Level 3 Ecoregion, which is a more general classification than Level 4) was best for birds. The model selections echoed what I found in the other analyses: fine-scale differences in patterns of bird movement were not detected. Region was a useful predictor of bat pass rates in the mixed models as well, indicating that a combination of local and regional variables are important in determining bat activity levels.

Some of the difference between bat and bird activity may be attributable to the different rates at which bats and birds vocalize. Bat echolocation is thought to be necessary for movement, although its use during migration is debated. Bird calls have a variety of purposes, but they are not necessary for movement. A bat vocalizes at different rates depending on its navigating or foraging mode, but calls are produced on the order of two to ten times per second (or faster when approaching prey). This is essentially a constant signal, and if bats echolocate the entire time they are flying, most or all bats flying within the range of a recorder should create a pass file. By contrast, a bird flying overhead might make no sounds for a period of time and avoid detection.

The dramatic variation in bird pass counts may also result from recorder placement and morning chorus calling. If a recorder is in a location preferable for mating, foraging, nesting, or stopover, it will likely pick up many post-sunset and pre-sunrise calls from non-migrating individuals that sing or call repeatedly. We very commonly encountered evening and morning chorus calling when visually verifying bird pass files. Although it was clear from looking at the sound files that these passes were not associated with migratory movements (e.g., repeated calling of constant loudness at regular intervals for an extended period of time), they were included in the analysis because 1) they indicate the presence of birds, whether in active migration or not, and 2) there is a fairly narrow window of time between the evening chorus and morning chorus, and if all but calls within this window were removed, pass rates would be reduced to zero for many sites.

Concentrated activity near coasts, especially during migratory movements is a pattern that has been well documented for long-distance migratory birds (e.g., Alerstam and Pettersson 1977, Bonter et al. 2009) but had not been substantiated for bats. Although the mechanism(s) driving this phenomenon are unknown, the findings of the Great Lakes comparisons add to our general understanding of bat migration, a poorly understood topic. The findings may also be useful in

identifying Great Lakes coastal areas as particularly risky for wind energy development with respect to impacts to bats.

Conclusion

Edges of all three forested river corridors in mostly agricultural settings in central and south-central Minnesota were found to host concentrated bat, and to a lesser extent, bird activity. Activity dropped off quickly with distance, as a gradient among edge, 200 m, and 500 m distances was apparent, but activity at distances past 200 m was relatively uniform. While activity levels varied greatly among distance groups at other array types, no clear patterns in bat or bird activity were observed at either grasslands in southwestern Minnesota or along the western shore of Lake Michigan.

One consistent observation for both bats and birds was that of substantially elevated activity at Great Lakes coastal sites compared with other sites. Of the 15 geographic regions we considered, the six Great Lakes regions had the highest average pass rates for both bats and birds. This is clearly an area of intense bat and bird movement during the migration seasons.

Bat activity during migration was greater in Great Lakes coastal regions than in any of the other regions in this study. This elevated activity was most intense at the northern end of Lake Michigan, but high pass rates were relatively consistent throughout the Great Lakes coastal region. Activity was concentrated in areas relatively close to shorelines; recordings taken 45 km inland had lower activity than nearby coastal sites (Figure 22).

Development potential for wind energy is very high in coastal areas such as along the Great Lakes. The observed activity levels indicate that risks to bats from wind energy development are likely higher in the Great Lakes than in other regions included in this study. I suggest that aerial wildlife generally, and bat populations specifically will benefit if the wind industry as well as wildlife managers and permitting agencies take extra caution when evaluating Great Lakes coastal areas for development.

Distance to water, the inverse of distance to trees, and Level 4 Ecoregion were included in the top model of bat activity among all sites, a model which explained much of the variation in pass rates (adjusted $R^2 = 0.66$). Level 3 Ecoregion was the only predictor included in the top model for

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birds, which performed relatively poorly. Patterns in bat activity were evident at both the local and regional scales, whereas patterns in bird activity were evident only at the coarsest geographic scale.

Bat activity is clearly dependent on both local and regional factors. The two-step modeling procedure of identifying local effects first and including them as random effects in a mixed effects model with region as the fixed effect allowed me to tease out the influence of geography among other potentially confounding effects. The areas around the Great Lakes included in the analysis generally have more suitable bat habitat, with higher density of trees and water than the sites in central and southwestern Minnesota I studied. However, the modeling results suggest that activity in that region exceeds what would be expected given the local habitat characteristics around those recorders. This analysis highlighted the importance of recognizing the combined contributions of effects at greatly different scales to variation in activity levels, as well as the importance of measuring activity across a large geographic range.

Table 7: Results of Tukey's HSD comparisons among distance groups for bats. Each letter represents a finding of significant difference in activity level at a particular site. Green cells are comparison results that, if significant, would support the hypothesis that pass rates are higher near the edge, while red cells are significant findings of the opposite (recorders at greater distances from the edge having higher pass rates). A letter in a cell means that the column heading distance had higher activity than the distance of that row for the location listed. For example: "Edge was higher than 200 m at Jackson, Martin, and Rockville."

(a) Forested River Corridors: J = Jackson County array, M = Martin County array, and R = Rockville County Park array

(b) Grasslands: B = Blue Mounds array, T = Tall Grass array

(c) Great Lakes: Be = Belgium array, K = Kewaunee array, P = Point Beach array

(a) Bats at Forested Corridors

	Edge	200m	500m	1500m	5000m
Edge					
200m	J M R				
500m	J M R			R	
1500m	J M R				
5000m	J M				

(b) Bats at Grasslands

	Edge	200m	500m	1500m	500m
Edge				B T	
200m				B T	
500m				B T	
1500m					
5000m				B T	

(c) Bats at Lake Michigan

	Coast	5km	10km	16km
Coast		K	K	Be
5km	P		K P	Be P
10km	P			Be
16km	P	K	K	

Table 8: Results of Tukey's HSD comparisons among distance groups for birds. Each letter represents a finding of significant difference in activity level at a particular site. Green cells are comparison results that, if significant, would support the hypothesis that pass rates are higher near the edge, while red cells are significant findings of the opposite (recorders at greater distances from the edge having higher pass rates). A letter in a cell means that the column heading distance had higher activity than the distance of that row for the location listed. For example: "Edge was higher than 200 m at Martin and Rock."

(a) Forested River Corridors: J = Jackson County array, M = Martin County array, and R = Rockville County Park array

(b) Grasslands: B = Blue Mounds array, T = Tall Grass array

(c) Great Lakes: Be = Belgium array, K = Kewaunee array, P = Point Beach array

(a) Birds at Forested Corridor

	Edge	200m	500m	1500m	5000m
Edge			J		
200m	M R		J		
500m	M R			R	
1500m	M R		J		
5000m	M		J		

(b) Birds at Grasslands

	Edge	200m	500m	1500m	500m
Edge			B	B	
200m	T		B	B	
500m	T				
1500m	T				
5000m	T		B	B	

(c) Birds at Lake Michigan

	Coast	5km	10km	16km
Coast		Be		Be
5km	P			Be P
10km	K P	K Be		Be
16km	K P	K		

Figure 15: Mean bat pass rates among distance arrays. Bars represent site mean, with 95% confidence intervals based on the variance in nightly pass counts and the number of recorded nights. Note differences in y-axis scales. Pass rates are clearly elevated at edge locations at forested river corridor arrays, but variation in activity at other array types does not appear to be related to distance from edge.
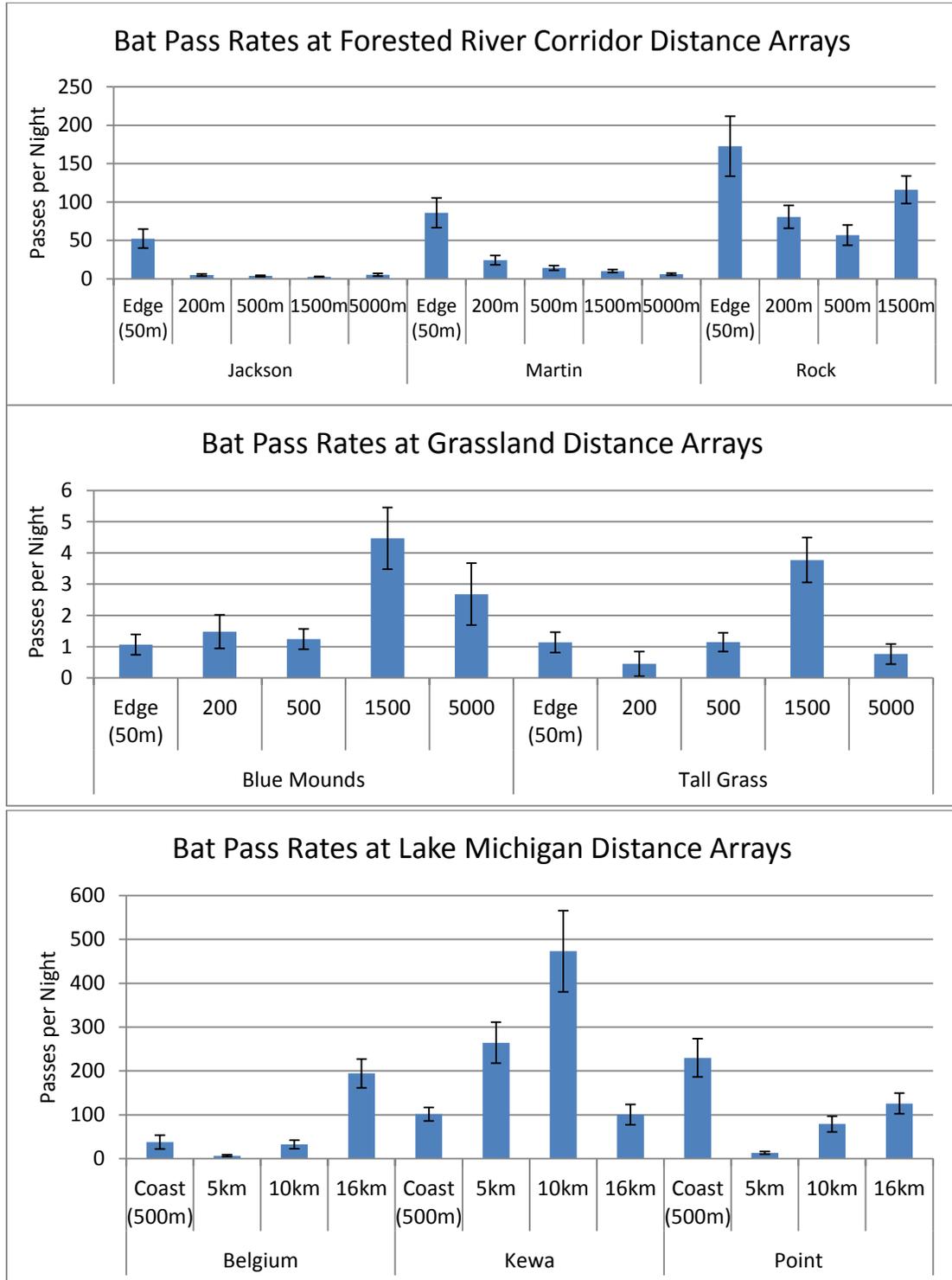
Figure 16: Estimated pass rates of eight focal bat species at forested river corridor (a), grassland (b), and Lake Michigan (c) distance arrays. These are the eight species included in the automated species identification process. Error bars represent error associated only with the species identification process. They are 95% confidence intervals for the mean nightly pass rate under the assumption of accurate pass rate estimates for each site. They do not include the uncertainty associated with the overall site mean, which is incorporated into the confidence intervals in Figure 15.

(a)

(b)

Pass Rates of Eight Focal Species at Grassland Arrays

(c)

Pass Rates of Eight Focal Species at Lake Michigan Arrays
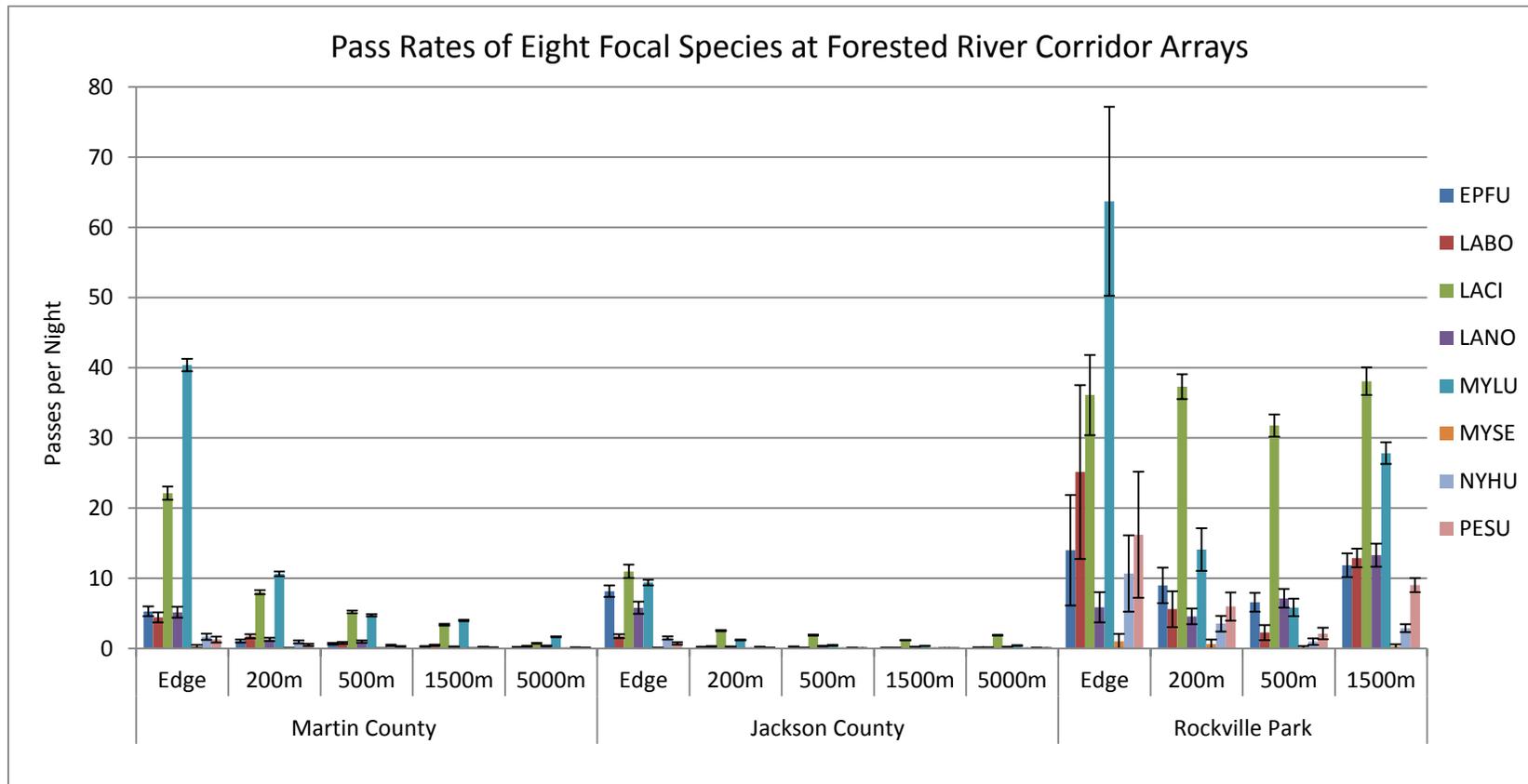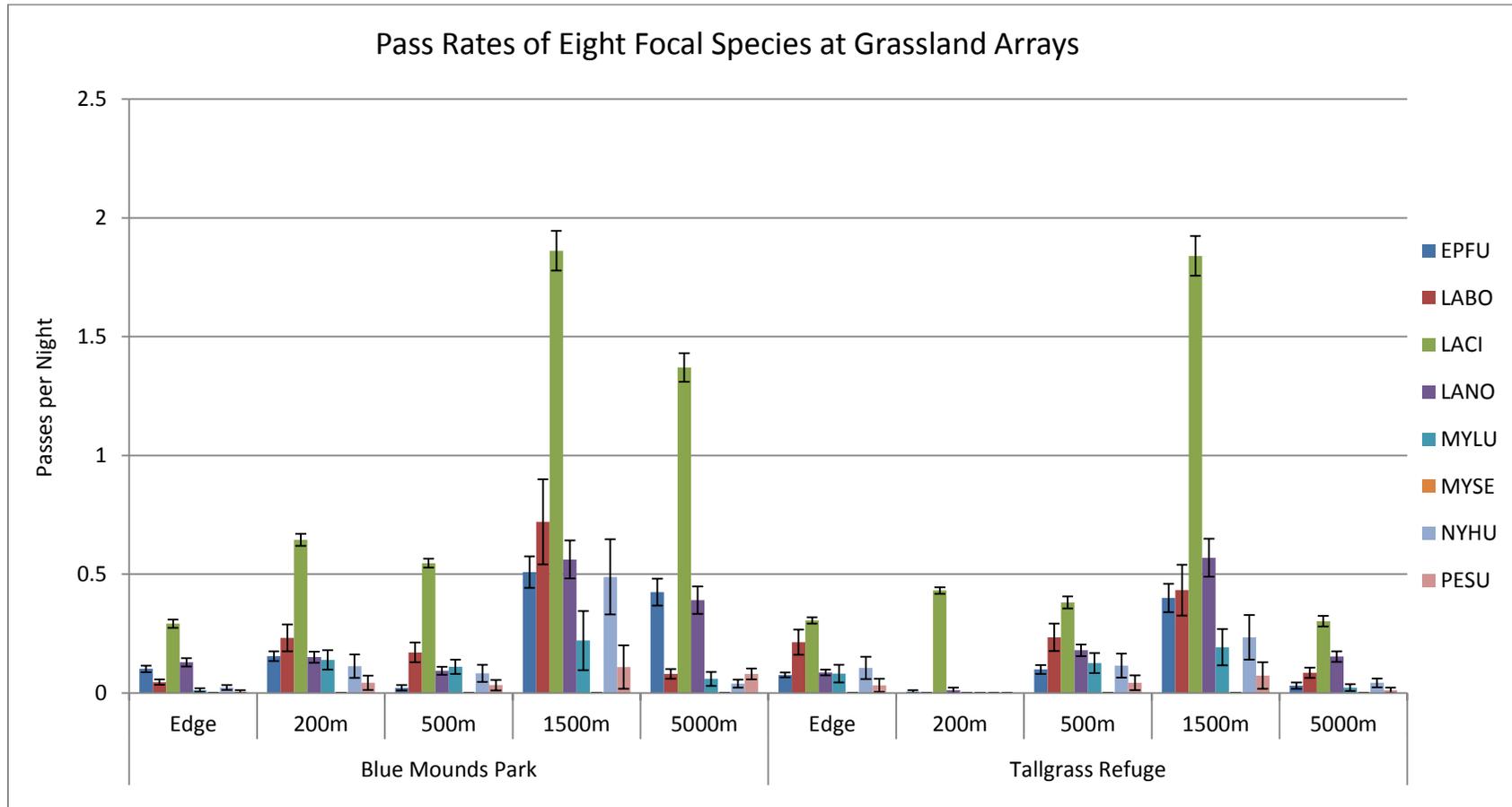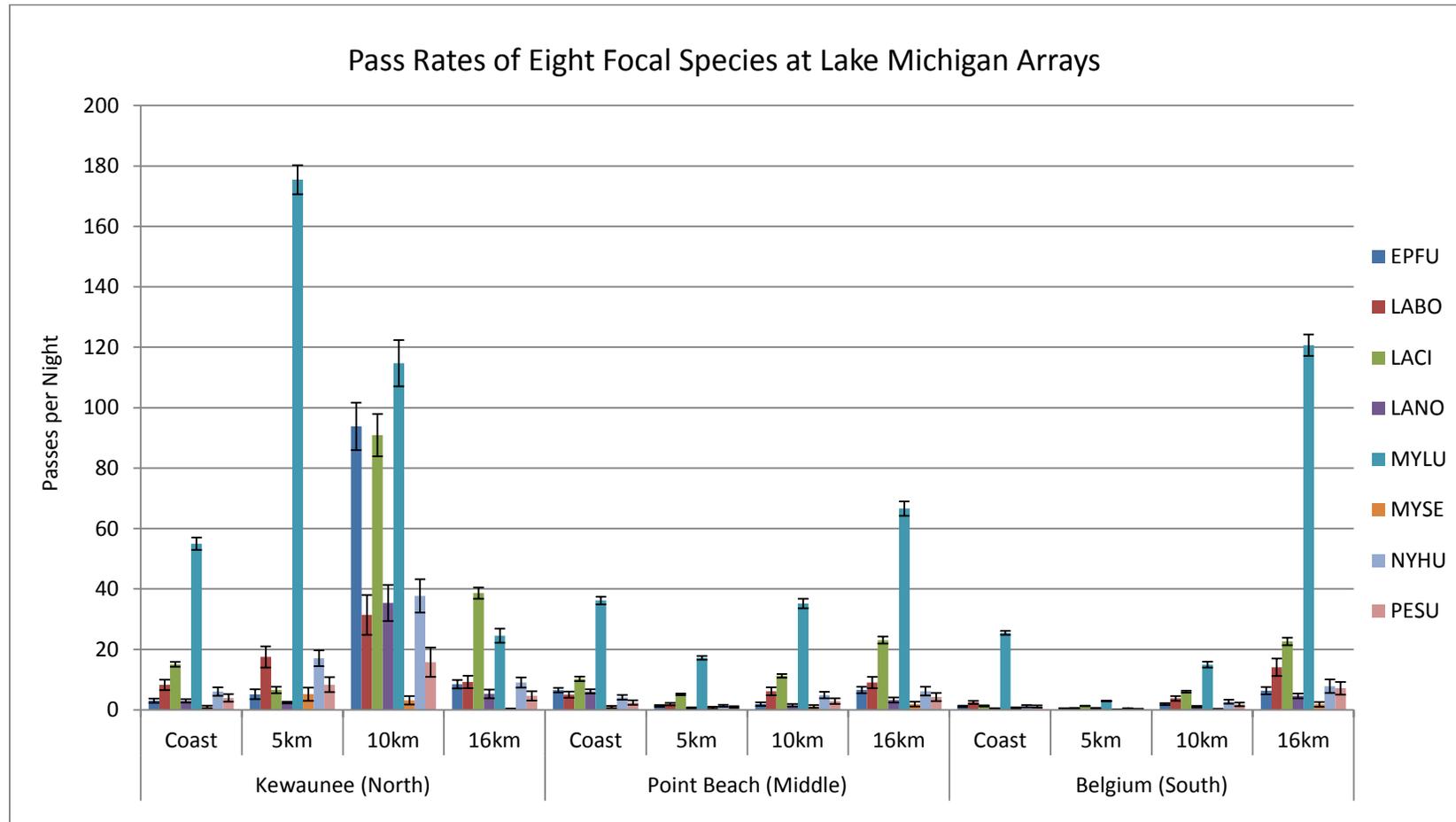
Figure 17: Estimated pass rates of the three migratory tree-roosting species common in the Upper Midwest at forested river corridor (a), grassland (b), and Lake Michigan (c) distance arrays. These species may be more susceptible to wind turbine collisions than other species. Error bars represent error associated only with the species identification process. They are 95% confidence intervals for the mean nightly pass rate under the assumption of accurate pass rate estimates for each site. They do not include the uncertainty associated with the overall site mean, which is incorporated into the confidence intervals in Figure 15.

(a)

(b)

Pass Rates of Migratory Tree Bats at Grassland Arrays

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(c)

Pass Rates of Migratory Tree Bats at Lake Michigan Arrays
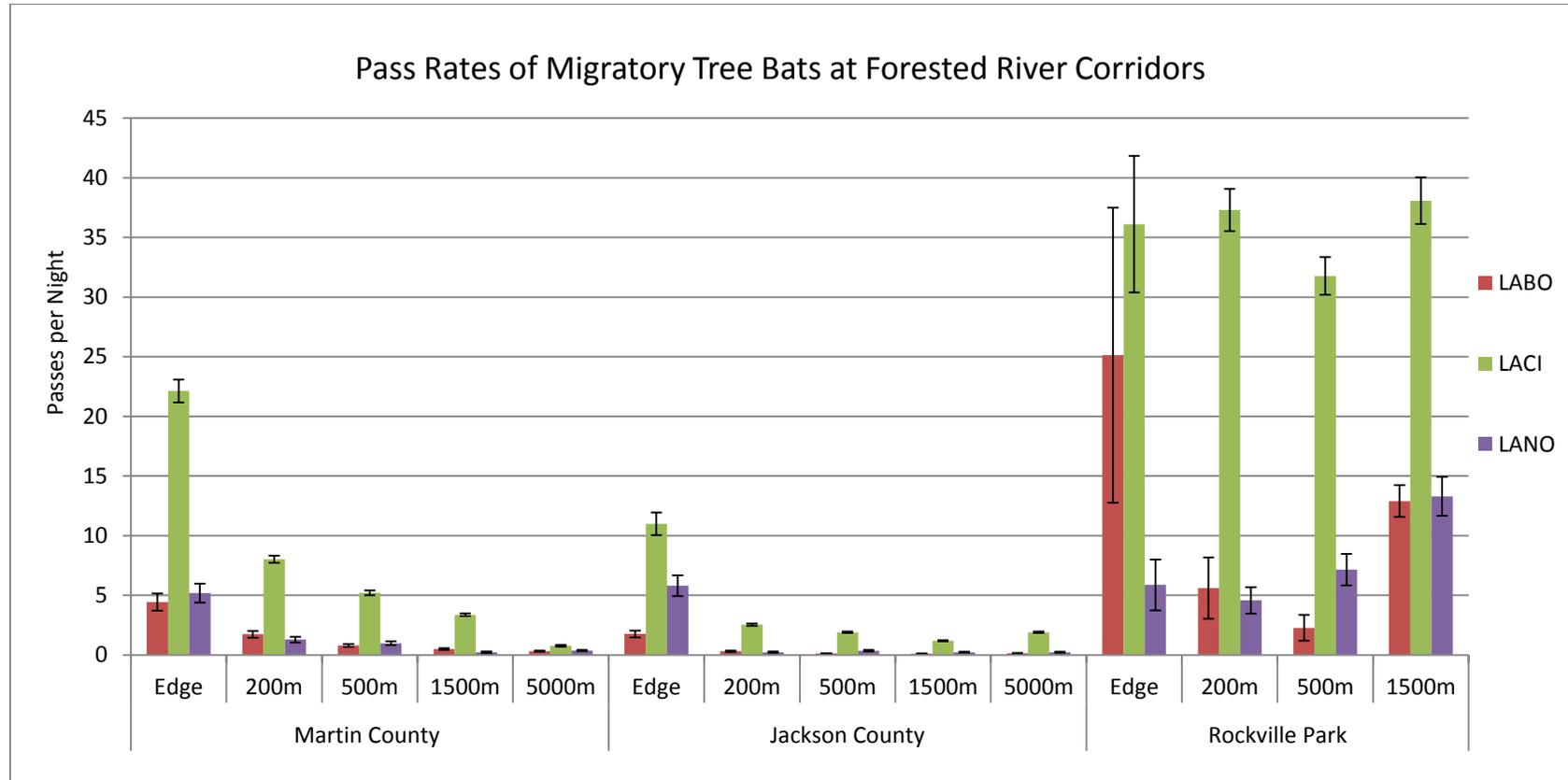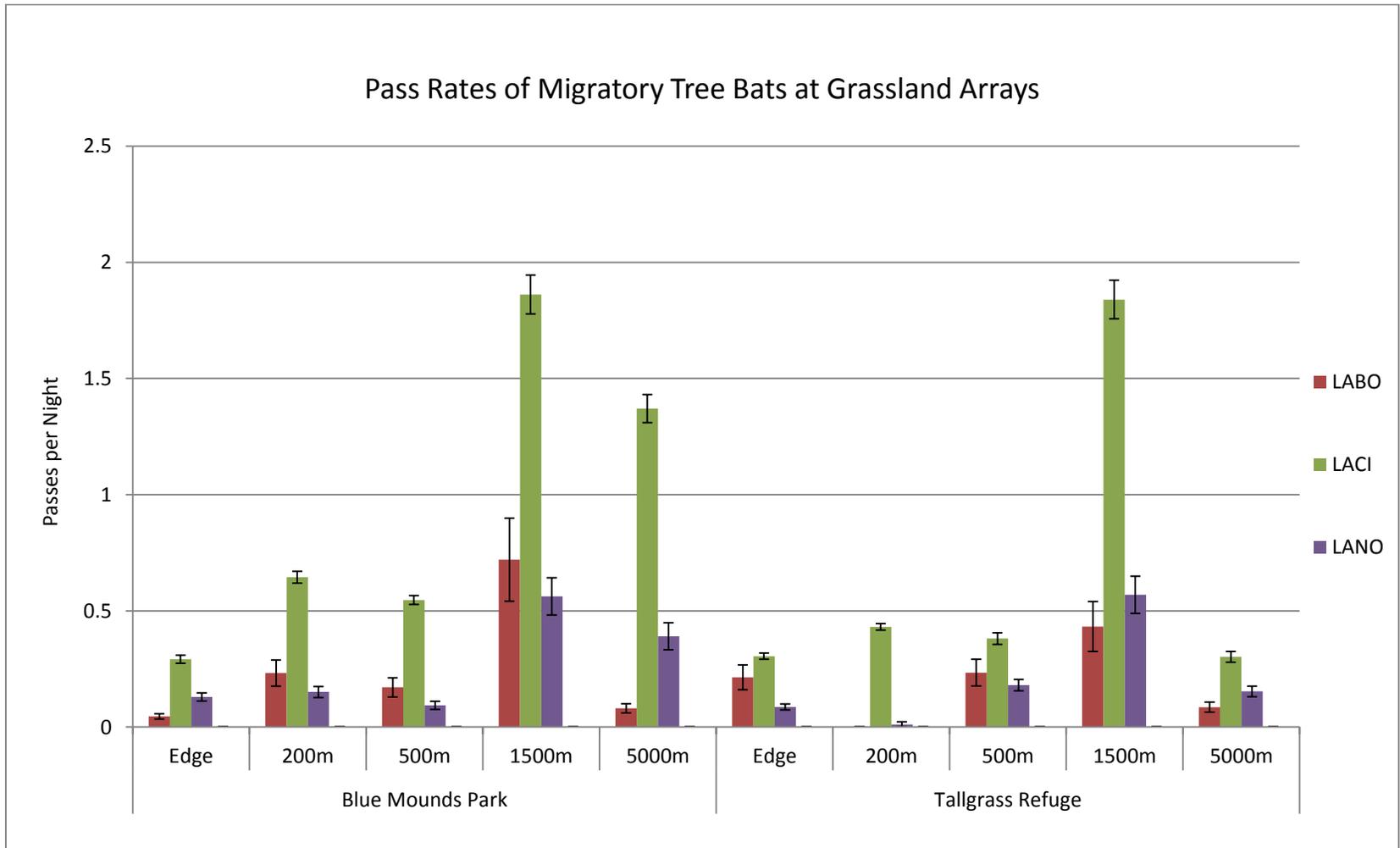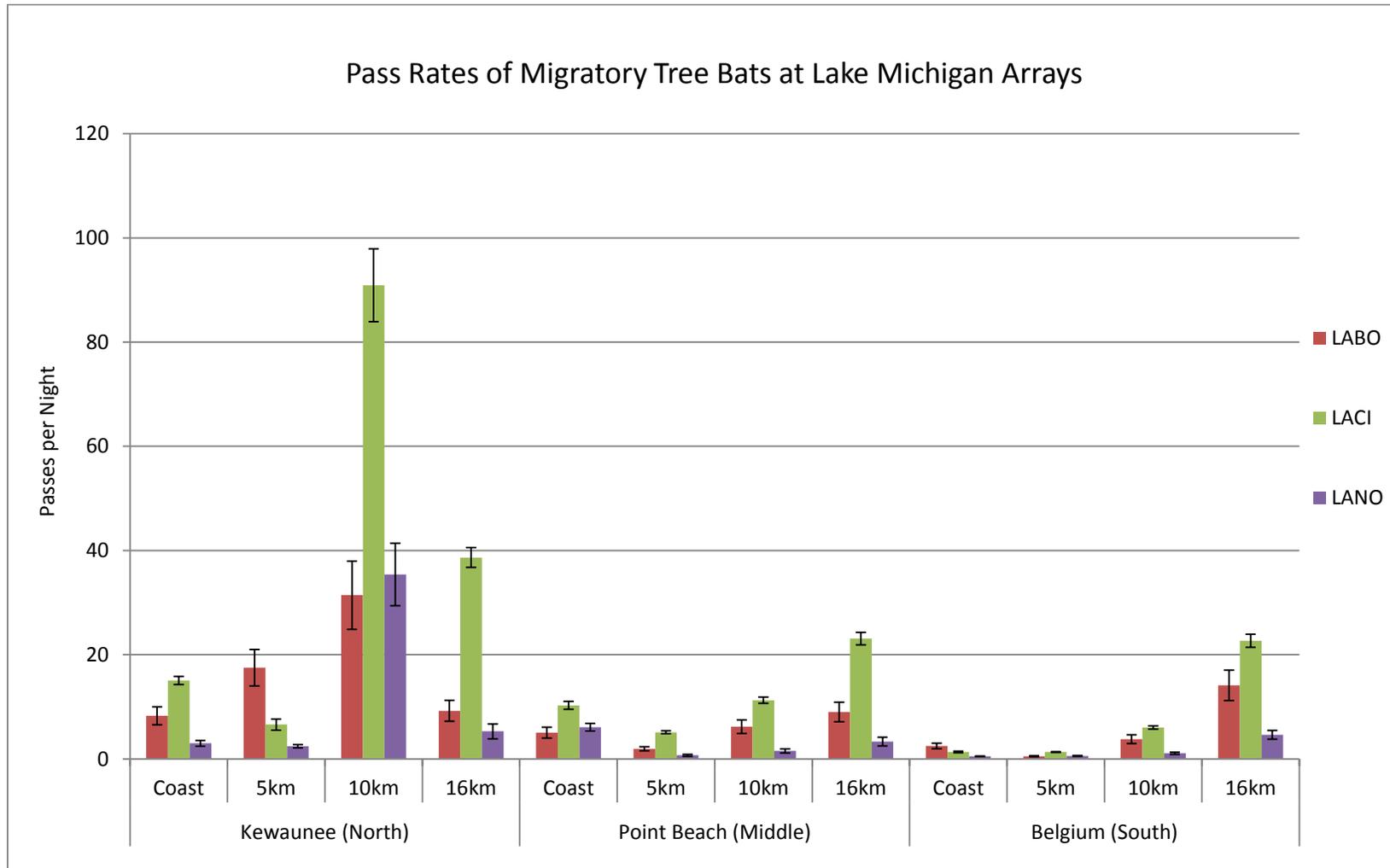
Figure 18: Mean bird pass rates among distance arrays. Bars represent site mean, with 95% confidence intervals based on the variance in nightly pass counts and the number of recorded nights. Note differences in y-axis scales. There may be some effect of distance to edge at the Martin forested river corridor array, and pass rates at the Lake Michigan Kewaunee array appear to decrease systematically with distance, however these results are not consistent among locations.
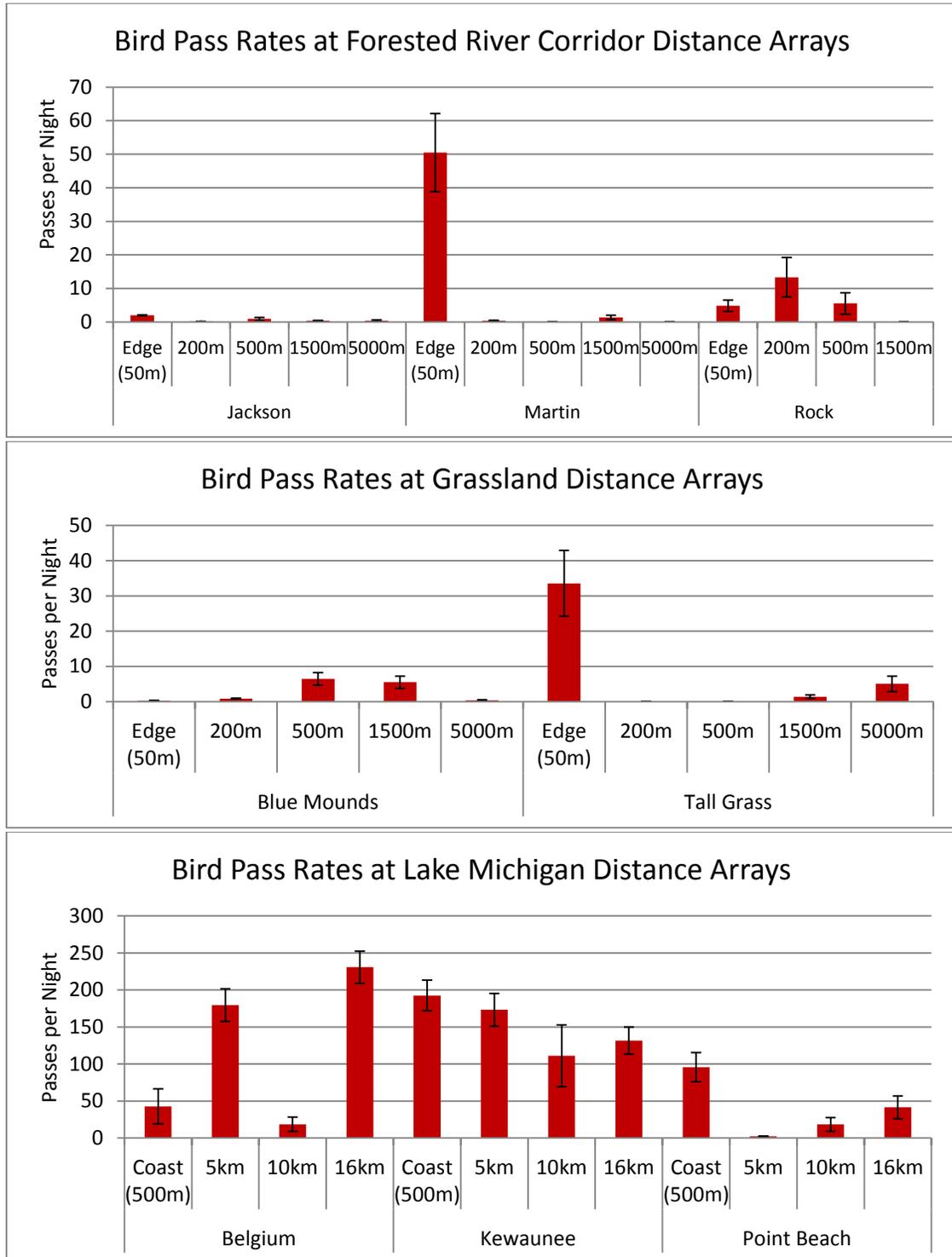
Table 9: AIC for bat pass models. The response variable was log-transformed site means. Models were ranked by AIC. Water = distance to water, Trees = distance to trees, Water^{-1} = inverse distance to water, Trees^{-1} = inverse distance to trees, Eco3 = EPA Level 3 Ecoregion (as a factor), Eco4 = EPA Level 4 Ecoregion (as a factor), df = degrees of freedom. * Indicates an interaction term with two variables.

Bat Model Selection Using AIC			
Model Name	**Variables included in model**	**df**	**ΔAIC**
lnm_witef	Water , Trees^{-1}, Eco4	27	0.00
lnm_wtef	Water, Trees, Eco4	27	1.34
lnm_witxef	Water, Trees^{-1}, Water * Trees^{-1}, Eco4	28	1.94
lnm_wtxef	Water, Trees, Water*Trees, Eco4	28	2.27
lnm_iwtef	Water^{-1}, Trees, Eco4	27	11.76
lnm_iwitef	Water^{-1}, Trees^{-1}, Eco4	27	12.67
lnm_iwtxef	Water^{-1}, Trees, Water^{-1}*Trees, Eco4	28	12.92
lnm_ef	Eco3	25	13.5
lnm_iwitxef	Water^{-1} , Trees^{-1}, Water^{-1} * Trees^{-1}, Eco4	28	14.55
lnm_witet	Water, Trees^{-1}, Eco3	15	94.84
lnm_witxet	Water, Trees^{-1}, Water * Trees^{-1}, Eco3	16	96.32
lnm_iwitet	Water^{-1} , Trees^{-1}, Eco3	15	97.78
lnm_wtet	Water, Trees, Eco3	15	98.34
lnm_iwtxet	Water^{-1}, Trees, Water^{-1}*Trees, Eco3	16	98.99
lnm_iwitxet	Water^{-1} , Trees^{-1}, Water^{-1} * Trees^{-1}, Eco3	16	99.36
lnm_wtxet	Water, Trees, Water*Trees, Eco3	16	99.75
lnm_iwtet	Water^{-1}, Trees, Eco3	15	99.96
lnm_et	Eco4	13	101.84
lnm_wit	Water, Trees^{-1}	4	131.07
lnm_witx	Water, Trees^{-1}, Water * Trees^{-1}	5	132.35
lnm_iwit	Water^{-1} , Trees^{-1}	4	138.86
lnm_iwitx	Water^{-1} , Trees^{-1}, Water^{-1} * Trees^{-1}	5	138.97
lnm_wt	Water, Trees	4	144.61
lnm_wtx	Water, Trees, Water*Trees	5	145.63
lnm_iwtx	Water^{-1}, Trees, Water^{-1}*Trees	5	148.57
lnm_iwt	Water^{-1}, Trees	4	150.06

Table 10: AIC table for bird pass model. The response variable was log-transformed site means. Models were ranked by AIC. Water = distance to water, Trees = distance to trees, $Water^{-1}$ = inverse distance to water, $Trees^{-1}$ = inverse distance to trees, Eco3 = EPA Level 3 Ecoregion (as a factor), Eco4 = EPA Level 4 Ecoregion (as a factor), df = degrees of freedom. * Indicates an interaction term with two variables.

Bird Model Selection Using AIC			
Model Name	**Variables included in model**	**df**	**ΔAIC**
lnm_et	Eco3	23	0.00
lnm_wtef	Water, Trees, Eco4	25	0.46
lnm_witef	$Water^{-1}$, $Trees^{-1}$, Eco4	25	0.49
lnm_iwtef	$Water^{-1}$, Trees, Eco4	25	1.43
lnm_witxef	Water, $Trees^{-1}$, Water * $Trees^{-1}$, Eco4	26	1.84
lnm_iwitef	Water, $Trees^{-1}$, Eco4	25	1.84
lnm_wtxef	Water, Trees, Water*Trees, Eco4	26	2.24
lnm_iwtxef	$Water^{-1}$, Trees, $Water^{-1}$*Trees, Eco4	26	3.20
lnm_iwitxef	$Water^{-1}$, $Trees^{-1}$, $Water^{-1}$ * $Trees^{-1}$, Eco4	26	3.66
lnm_witxet	Water, $Trees^{-1}$, Water * $Trees^{-1}$, Eco3	15	22.96
lnm_witet	Water, $Trees^{-1}$, Eco3	14	23.15
lnm_iwitet	$Water^{-1}$, $Trees^{-1}$, Eco3	14	23.18
lnm_iwitxet	$Water^{-1}$, $Trees^{-1}$, $Water^{-1}$ * $Trees^{-1}$, Eco3	15	25.08
lnm_et	Eco4	12	25.52
lnm_wtet	Water, Trees, Eco3	14	26.47
lnm_iwtet	$Water^{-1}$, Trees, Eco3	14	26.79
lnm_wtxet	Water, Trees, Water*Trees, Eco3	15	27.16
lnm_iwtxet	$Water^{-1}$, Trees, $Water^{-1}$*Trees, Eco3	15	28.77
lnm_iwt	$Water^{-1}$, Trees	4	37.38
lnm_wt	Water, Trees	4	37.39
lnm_wit	Water, $Trees^{-1}$	4	38.13
lnm_iwit	$Water^{-1}$, $Trees^{-1}$	4	38.28
lnm_wtx	Water, Trees, Water*Trees	5	38.43
lnm_witx	Water, $Trees^{-1}$, Water * $Trees^{-1}$	5	38.44
lnm_iwtx	$Water^{-1}$, Trees, $Water^{-1}$*Trees	5	39.25
lnm_iwitx	$Water^{-1}$, $Trees^{-1}$, $Water^{-1}$ * $Trees^{-1}$	5	40.06

Figure 19: Residual plots for top bat model (lnm_witef), colored by region. The random distribution of residuals indicates that the top model likely includes the most useful explanatory variables. Relatively constant variance suggests that the log-transformation was effective in controlling for increasing variance among pass rates.
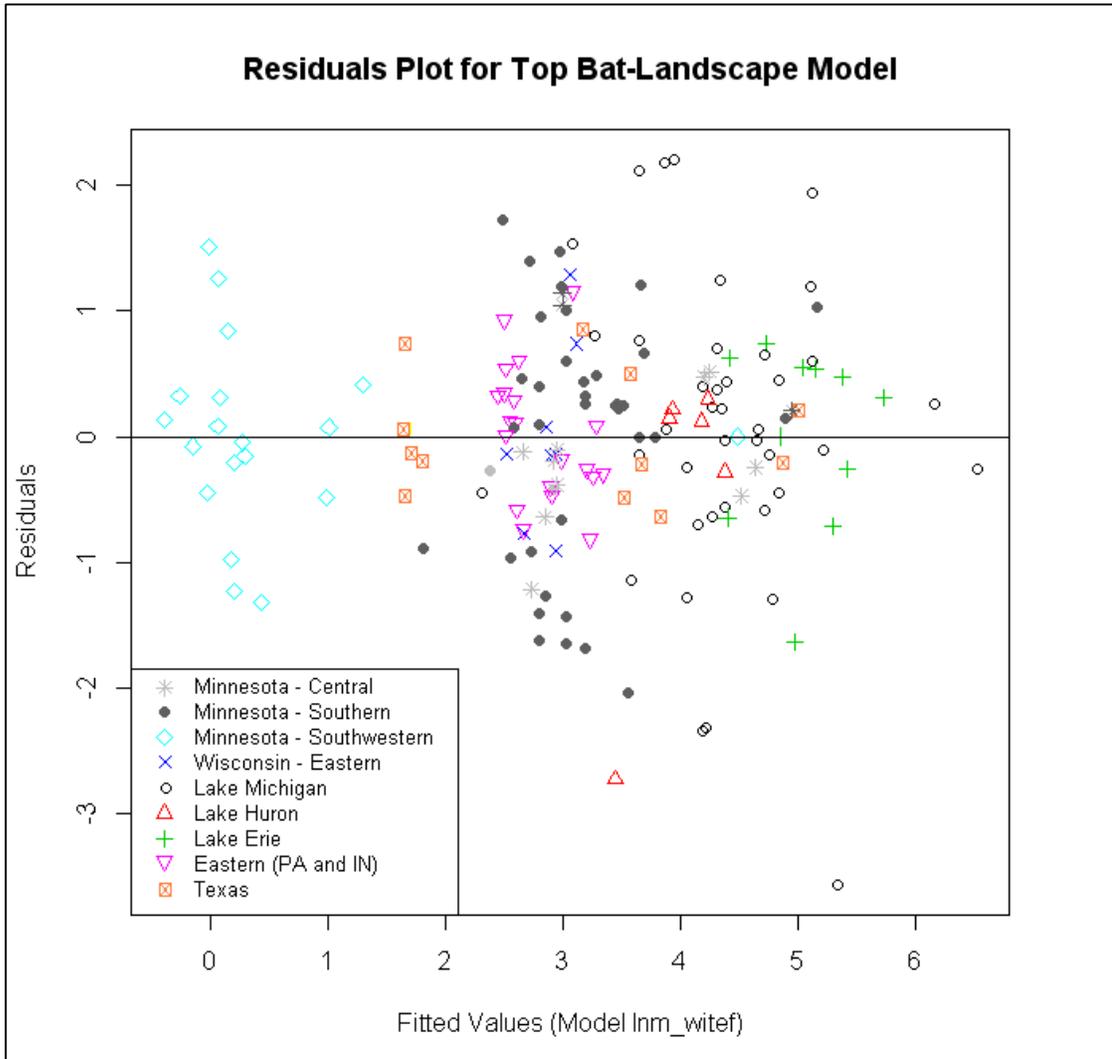
Figure 20: Residual plots for top bird model (lnm_et), colored by region. The vertical alignment of residuals is a result of the top model containing only a single categorical variable (Level 4 Ecoregion), resulting in a single fitted value for each region. A slight downward trend may be evidence that an unobserved or excluded variable might have the potential to improve the model. Relatively constant variance suggests that the log-transformation was effective in controlling for increasing variance among pass rates.
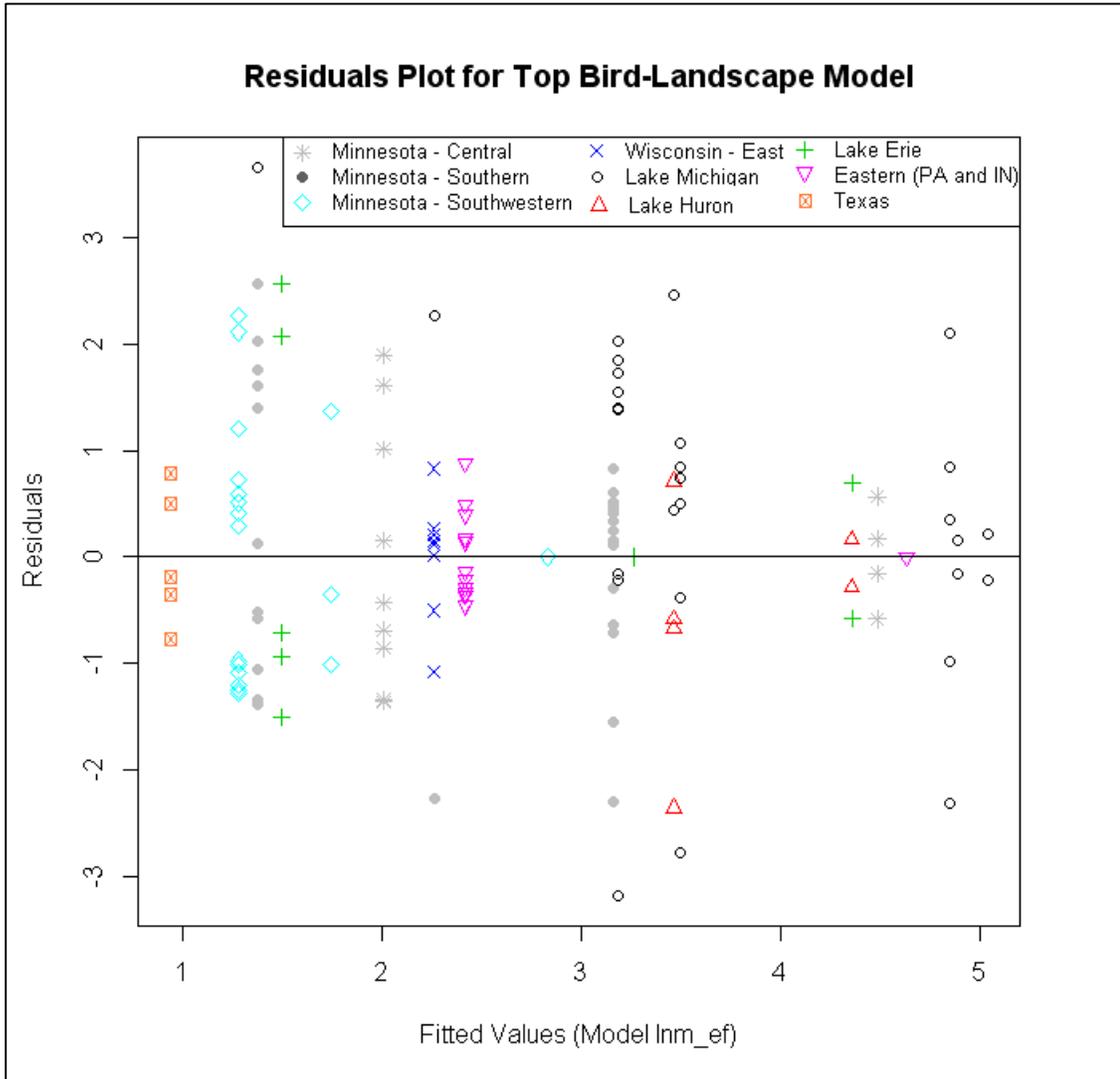
Figure 21: Mean bat and bird passes per night by region. The number of recording sites in each region is in parentheses. Error bars represent 95% confidence intervals for the estimated overall bat or bird activity level in that region. These errors are large for regions with few recorders because each site mean is considered one sample in this analysis. Great Lakes recording locations make up the six highest activity regions for both bat and bird pass rates, and are outlined in green.
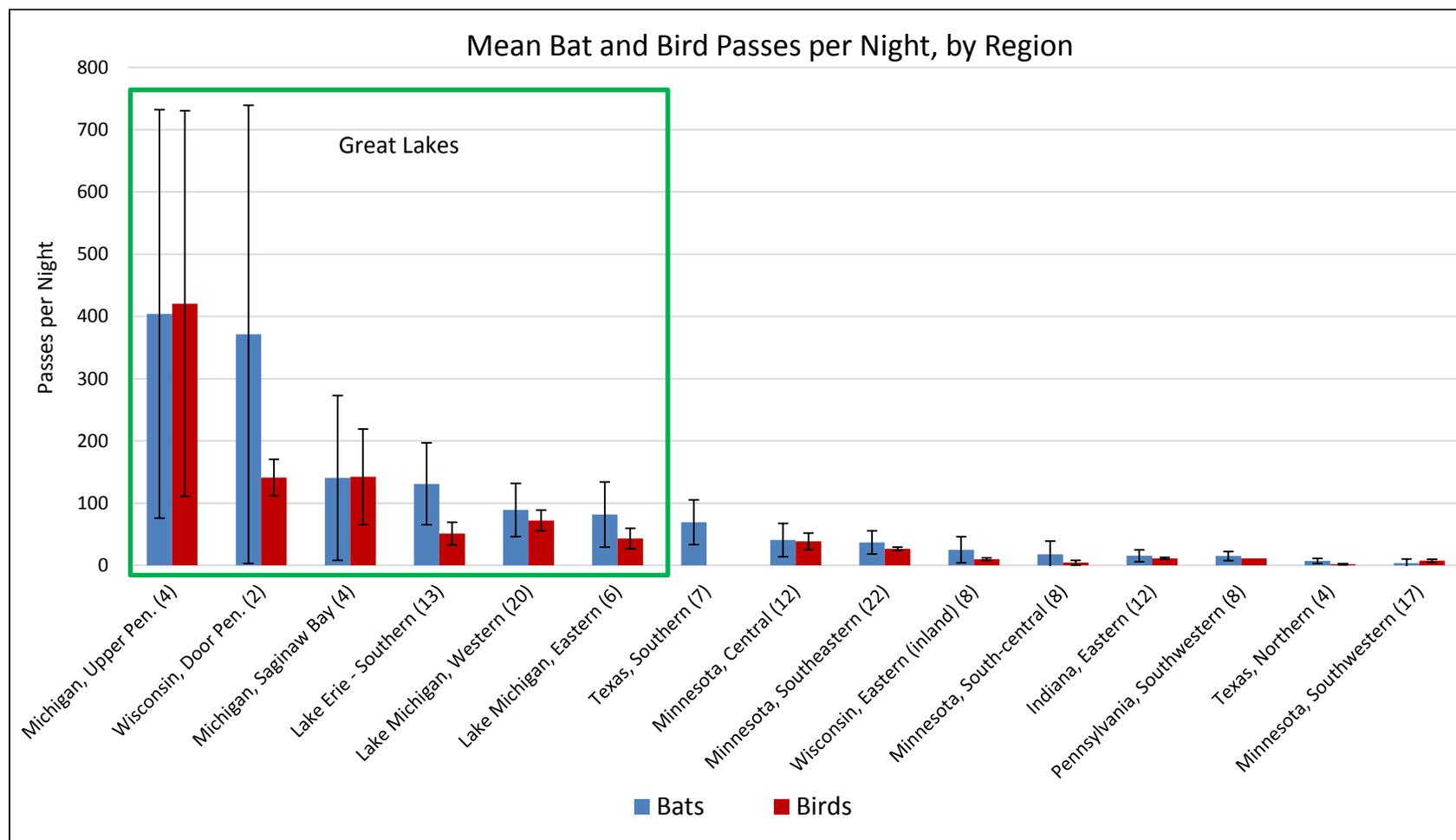
Figure 22: Mean nightly bat pass rates at sixteen Lake Michigan recording sites and eight inland sites used in the second comparison of bat activity between Great Lakes coastal sites and inland sites. Circle radii are proportional to the mean pass rate, which is listed in white. Underlying geographic imagery © Google Earth.
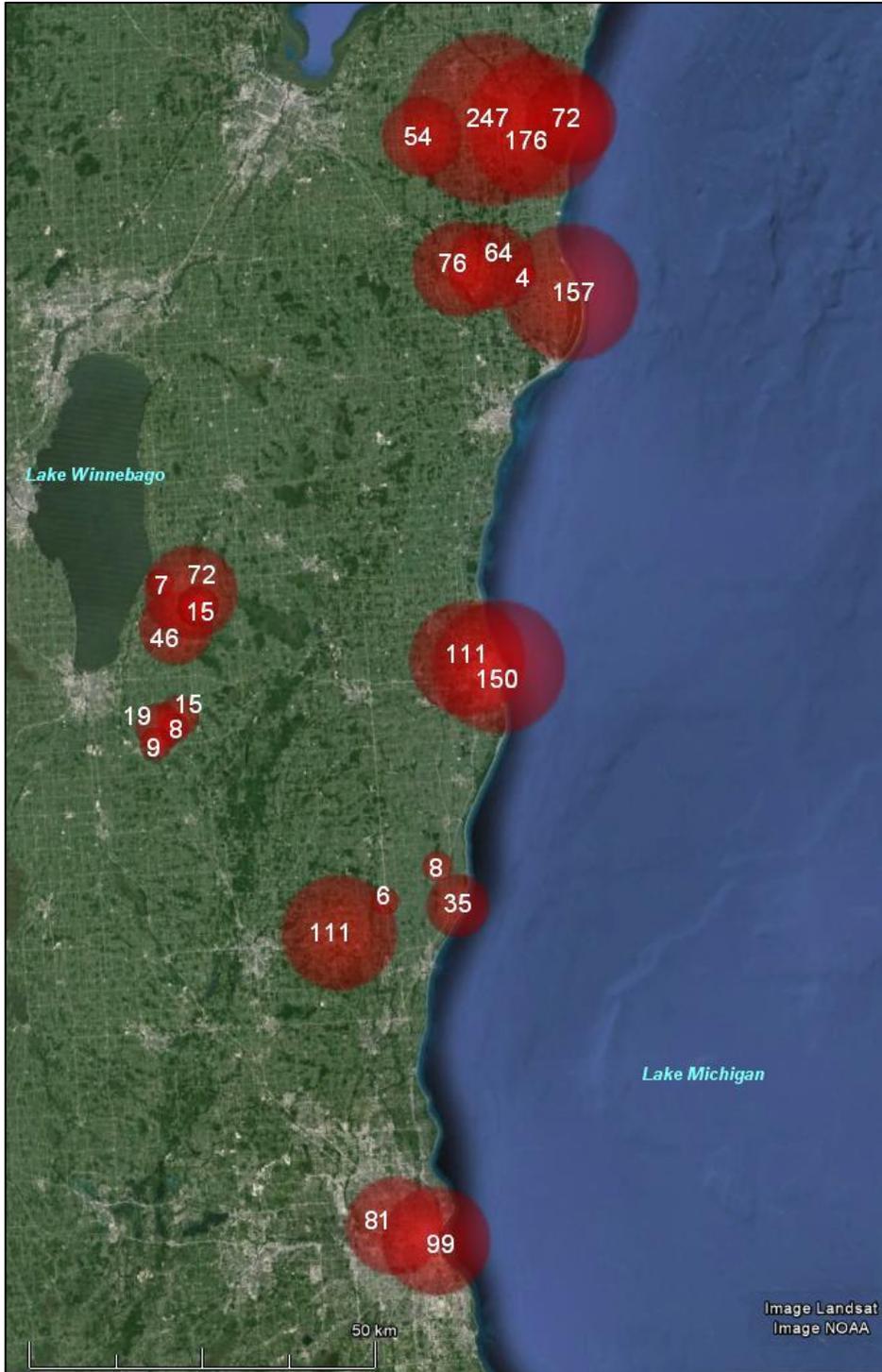
Chapter 3: Effects of Wind Farms and Turbines on Pass Rates

Introduction

A common thread in the results of wind-wildlife research is that fatalities are not random. Bird fatality rates are related to certain aspects of turbine design such as tower structure and height (Longcore 2008) and likely geography (Loss 2013). Bat fatalities vary by season, life history (i.e., migration) and perhaps geography as well (Arnett and Baerwald 2013).

At the local scale, possible effects of wind farms and turbines themselves include 1) avoidance by birds and 2) attraction by bats. Raptors perching on lattice-tower turbines at Altamont Pass could be considered attraction by birds (Smallwood and Thelander 2005), but the lattice tower design is now obsolete and was not considered here.

Avoidance of wind turbines by birds has been documented with a variety of species, and in multiple regions and habitats. Radar has been used to document flight avoidance among water birds at an offshore wind farm in Denmark (Desholm and Kahlert 2005). Visual surveys have documented avoidance of turbines among some breeding songbirds in North Dakota grasslands (Shaffer and Johnson 2008), several upland breeders in the United Kingdom (Pearce-Higgins et al. 2009), and eagles in coastal Tasmania (Hull and Muir 2013).

Attraction of bats to turbines has been a long-standing hypothesis to explain high fatality rates at certain wind farms. Some studies have used night vision cameras to record bats flying around turbine blades and nacelles in what appears to be some kind of interaction (Horn et al. 2008, Cryan et al 2014). Speculation regarding the reason for this attraction to, or interaction with, turbines has produced a wide range of potential hypotheses, but aside from video clips and the fatalities themselves, there is little evidence that bats are actually attracted to turbines.

I attempted to answer two main questions regarding the effects of turbines on bats and birds that have not been addressed in previous studies. These questions are addressed by objectives 5 and 6, respectively.

1) Does the development of a wind farm affect activity levels for birds or bats at the site?

2) Is bat activity higher near turbines, as might be expected with attraction?

Methods

Attraction or repulsion can be examined at two scales: the effect of an entire wind farm on long-distance or migratory movements, and the effect of individual turbines on short-distance or daily movements. Effects at the level of entire wind farms (objective 5) were examined in the Before/After study, and effects of individual turbines (objective 6) were examined in the Distance-to-Turbine study.

Before/After

To measure the effects of entire wind farms, I used a before/after comparison. I deployed recorders at prospective wind farm sites where developers had begun the permitting process at either the state or federal level. Prospective sites had to be far enough along in the planning process that the project was likely to proceed. I selected sites slated for development within two years of the spring of 2010. I gathered this information from the Federal Aviation Administration's queue of applications for determination of no hazard to air traffic (required for any structure over 61 meters tall; FAA 2014) and project development queues of electrical regional transmission operators (e.g., MISO 2014), and through communication with wind farm developers, the Minnesota Department of Commerce, and the Minnesota Department of Natural Resources.

Once three likely development sites were selected, recorders were set up beginning in the spring of 2011 to take pre-construction recordings of bat and bird acoustic activity at each location. The plan was to continue recording at the same sites within those locations after the project was constructed and examine any differences in general levels of bird or bat activity post-construction.

This is not a formal before-after control-impact (BACI) study, although elements of BACI theory (Smith 2002) were used in its design and may be used in subsequent analyses by viewing the study in the context of this entire research project. The before/after impact component was my main focus, since the existence of any effect of wind farms on acoustic activity was unknown. Another reason I did not attempt to select control sites to pair with before/after sites was

uncertainty regarding the criteria that control sites would need to meet. In the planning process, I did not know what kind of spatial or temporal variation in pass rates would be expected, which made the prospect of finding "comparable" sites seem impossible. If geographic proximity was used to guide site selection, it would require some knowledge of the distance at which wind farm effects no longer exist, which is likely different for birds and bats, and is not known in any case. However, if the purpose of control sites is to control for large-scale seasonal or annual variation, then the sites associated with other objectives (Chapters 1 and 2) would be a suitable substitute for designated control sites, and were used as such.

Study Sites

- Oak Glen is a 44 MW facility with 28 turbines, spanning about 9 km^2 in southeastern Minnesota. It is mostly farmland, bordered by three wildlife management areas and a 0.5 km^2 lake at the northeast corner. Development throughout the autumn of 2011 led to project completion near the end of October that year. Since project completion occurred at the end of my study period, and after seasonally-dependent acoustic activity levels dropped, all of 2011 is considered a pre-construction year, and 2012 is considered a post-construction year.

- Paynesville is a wind energy project in central Minnesota planned to have a capacity of 95 MW and up to 60 turbines. The setting is mostly cropland, dotted with a few small wildlife management areas and a large wetland complex in its southwest corner. The project went into construction shortly after data collection for this study ended.

- Prairie Rose is a recently completed 119-turbine, 200 MW project in southwestern Minnesota covering approximately 60 km^2 of mixed cropland and pasture. It is located about 10 km northwest of Blue Mounds State Park and a large section of the Northern Tallgrass Prairie National Wildlife Refuge.

Analysis

Using the results of the landscape analysis as evidence of similarity among large geographic regions, I compared before/after sites to other recording locations within their region (referred to as "10Region" in Appendix A). Analysis of before/after pass rates were carried out with a 2-way ANOVA on year (before vs. after construction), site (before/after treatment sites vs. other control sites), and the interaction between year and site. Only Minnesota and Iowa sites with recording data from both 2011 and 2012 were used. Recorders at these locations operated on the same seasonal schedule, so no seasonal adjustment was used in this analysis. Pass counts at the four

recorders at each location were averaged for each night, giving a nightly mean pass count for each location. A natural logarithm transformation was applied to this response variable to approximate normality, since overall site means are not normally distributed despite large sample sizes.

Distance-to-Turbine

To examine the potential attraction of bats to turbines at a smaller scale (within a wind farm), recorders were placed at specified distances from the base of operating turbines at two operating wind farms. Turbines near features such as tree rows, forest edges, culverts, watercourses, standing water, or anthropogenic structures that might influence pass rates were avoided for this study to limit potentially confounding factors. Four turbines dispersed throughout each facility were chosen and three recorders were set up at 50 m, 200 m, and 500 m from the base of the turbine. Fifty meters was used as the closest distance because it is the minimum distance I was allowed to access without being accompanied by wind farm personnel. Two hundred and 500 m were selected based on initial results from the landscape study (Chapter 2) as reasonable distances over which decreases in bat activity with distance from areas of concentrated activity could be detected.

Study Sites

- Fowler Ridge is a large wind farm in Indiana, described in Chapter 1 as a fatality study site. As the site of one of the few known turbine fatalities of the endangered Indiana bat (*Myotis sodalis*), it was studied as part of a collaborative effort among the USGS, Bat Conservation International, and the University of Minnesota, to examine bat activity near turbines using a variety of different technologies, including mobile radar, night-vision cameras, and at-height and ground-based recording.

- Grand Meadow is a 67-turbine, 100 MW capacity wind farm in southeastern Minnesota. It spans about 45 km^2 of cropland with few open water sources or managed lands, making it easy to place recorders at turbines with few potentially confounding landscape features. Also, turbines there are dispersed over a relatively large area, with gaps of entire 2.6 km^2 legal sections within its boundary. This was important because it allowed recorders to be placed such that 1) the farthest recorder was 500 m from the turbine of interest while also being more than 500 m from the next closest turbine, and 2) the array did not need to be near the border of the wind farm in order to avoid other turbines. This meant that the effect of

individual turbines, and not the wind farm as a whole, could be measured. Effects detected by arrays near the edge of a wind farm are not necessarily local attraction or repulsion, but may be a larger-scale effect of the entire facility.

Analysis

Initial steps included graphical examination of means and a one-way ANOVA of pooled pass rates by distance to examine the possibility of elevated bat activity near turbines. If pass rates were consistently higher at 50 m than the other locations, or rates at 50 m and 200 m were higher than 500m, there would be some evidence of elevated activity near turbines, supporting the attraction hypothesis.

Recording schedules at the two distance-to-turbine locations largely coincided during the study period (summer/autumn of 2012), so seasonal adjustment was not applied. Pass counts were, like those from all sites, highly skewed to the degree that even means of large sample size were also skewed. For this reason, the ANOVA was carried out with log-transformed means.

In addition to an ANOVA, mixed effects models were used to evaluate distance as a predictor of log-transformed pass counts at the distance-to-turbine arrays. Location (either Grand Meadow or Fowler Ridge) and turbine ID (indicating the location of the recording site within the wind farm) were included as random effects in models including and excluding both distance to turbine and inverse distance to turbine, since attraction effects might be expected to have non-linear response that decreases with distance. The AIC was used to rank models, and likelihood ratio p-values were used to determine significant differences in fit between models.

General Model of Effect of Turbines

In addition to the 24 recorders used in the distance-to-turbine arrays, any recorder located in a wind farm could be used to address the distance-to-turbine question. Recorders from the before-after study and the fatality study (Chapter 1) were included in an additional analysis in which each recorder's distance from the nearest turbine was used as a predictor of pass rates. In all, data from 66 recorders were used to model log-transformed mean pass rates as a function of distance from turbines for bats and birds. Since pass rates vary dramatically by region, region was included as a random-intercept effect. For this analysis, both distance and the inverse of distance were included as predictor terms, because activity might be expected to have a non-linearly decreasing response if attraction or repulsion effects are strong closest to the turbine but weaken

with distance. The AIC was used to rank models, and likelihood ratio p-values were used to test for significant differences in fit between models.

Results

Before-After

Oak Glen was the only before/after study site to be developed within the data collection period. Fortunately, recordings included an entire year of pre-construction activity and an entire year of post-construction activity. Nineteen sites fit the loose criteria for inclusion as pseudo-control sites in a BACI-style analysis of the effect of development at Oak Glen on bat and bird passes.

Bats

The two-way ANOVA indicated that bat pass rates were higher in the post-construction year 2012, and also were higher at the treatment location Oak Glenn (Figure 23). The interaction term had a small negative effect, but was not significant (p=0.099), which means there is little evidence in these data that the rise in activity between 2011 and 2012 was enhanced by the construction of a wind farm at Oak Glen at the end of 2011.

Bats by Species

Pass rates for hoary (LACI), and especially little brown (MYLU) bats were higher than other species and varied greatly among locations and between years (Figure 24). Pass rates for other species were relatively low within all groupings. As the ANOVA indicated, while there was an increase in activity at the treatment site between 2011 and 2012, there was a corresponding increase at the control sites, and the magnitude of change was slightly larger at the control sites, even for little brown bats, whose activity level doubled at the treatment site. The species pass rates are generally reflective of the overall pattern in pass rates for bats.

Birds

Oak Glen had higher bird pass counts as well, and the effect of year was also found to be significant and positive (Figure 25). The interaction was found to be negative and highly significant (coefficient -14.4, p = 0.007). These data give some indication that the wind farm may have had a negative effect on bird pass rates, however this finding is based on a single year of pre-construction data and a single year of post-construction data at one treatment site. Also, the "control" sites used in the analysis were not selected specifically as control sites and may in fact not be comparable.

Distance-to-Turbine

Bats

No significant difference in pass rates among the 8 x 3-recorder distance groups was detected (ANOVA p = 0.307), which is apparent in the Figures 26 and 27. Pass rates at all three distances were the same, relative to variation among turbines and wind farms. Two turbines (T480 at Fowler Ridge and T161 at Grand Meadow) show apparent avoidance by bats, with higher pass rates at greater distances. Most arrays did not have a consistent pattern of either higher or lower rates at closer distances, and none of the three distances had consistently high or low rates.

Bats by Species

As with cumulative pass rates, there is no clear pattern of attraction for any of the species (Figures 28, 29, and 30). Little brown bats (MYLU) have consistently high pass rates at most Grand Meadow recording sites, while the other species are fairly consistently low, with the exception of the 500 m distance at turbine 101. The 500 m recorder at Grand Meadow turbine 101 is not situated in a location that I would have expected to have high pass rates (e.g., it is not near trees or water or a building). I cannot offer any explanation for the increase in pass rates, especially for hoary bats (LACI) and the several other species that are less common at other sites.

In contrast to the lopsided species composition at Grand Meadow, Fowler Ridge had much more even species representation across sites. Eastern red bats (LABO) were most common at several recording sites, and most species have substantial activity levels, with the exception of relatively rare northern myotis (MYSE) and big brown bats (EPFU).

Distance-to-Turbine Models

Neither distance to turbine nor inverse distance to turbine was found to be a particularly useful predictor of bat pass counts. Although a model with inverse distance ranked highest, its fit was only slightly better than a null model with no distance term (ΔAIC = 4, likelihood ratio p-value = 0.011). Additionally, distance and inverse distance terms were not significant in models including them (p = 0.133 and 0.162, respectively).

General Model of Effect of Turbines

This analysis used bat and bird data from all 66 recorders placed within wind farms, combining data from recorders associated with the fatality study, the before/after study, and the distance-to-turbine study. Plots of log-transformed mean pass count vs. distance from the nearest turbine do

not reveal any clear pattern, although pass rates do seem to rise slightly at greater distances (Figure 31). Linear regression using distance and the inverse of distance as predictors of pass rates identified distance, but not its reciprocal, as a significant predictor (p = 0.006 and 0.049 for bats and birds respectively) with positive effects, but neither model explained much of the variation in pass counts (adjusted R^2 = 0.09 and 0.05 for bats and birds respectively).

Discussion

I found some limited support for avoidance of wind farms by birds. Whereas some results for bats indicated significant effects, they suggested slight avoidance rather than attraction. Evidence for the effect of wind facilities on pass rates was not overwhelming in any case, and further study would be needed to confirm the patterns observed here.

It is important to put significance levels into perspective for these results. Two aspects of this study, and of the entire project in general, make statistical significance less meaningful here. One is the size of the data set, which allows for large sample sizes in most comparisons or models, which results in small calculated errors and high precision. With small enough standard errors, any difference between means becomes significant (Johnson 1999). Additionally, the number of questions I was asking was large, and most were twofold (for bats and birds), which meant there were many opportunities to find significant results. In this study alone, six tests concerning the effect of wind facilities on pass rates were conducted, so a Bonferroni-corrected significance level 0.008 might be a more appropriate threshold. For these reasons, I have tried to include visual representations of the data to allow for a more direct interpretation of results and to illustrate the magnitude of observed differences.

Patterns of avoidance or attraction may be difficult to detect from ground level recordings. For bats, there is some evidence that activity patterns vary with height (Baerwald and Barclay 2009). The short reception range of ultrasonic recorders meant that ground-recorded pass rates likely differ from at-height pass rates, and any elevated activity resulting from attraction may have been beyond this range.

Ground-based recording is problematic for surveying bird activity as well, but for different reasons. The types of vocalizations recorded (more often songs than chip notes), and the repetition of calls observed indicate that most of the passes were likely from perched birds near

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the ground, rather than migrating birds passing overhead. Most calls were recorded in the morning and evening, with a lull in the middle of the night. This also indicates that the passes were associated with crepuscular activity of birds near the recorder. These birds may be migrants, and the activity observed may be associated with migratory movements, but the bulk of the vocalizations are likely not birds that are actively migrating.

Conclusion

Only one of the three wind farms I studied for the before/after comparisons actually was completed during this study, which severely limited the amount of post-construction data at locations studied prior to construction. At that single site, I found some evidence that bird activity decreased when a wind farm was built, compared with four pseudo-control locations within the same region.

In the distance-to-turbine study, no clear patterns are evident in graphical representations of the data, and test results were based on relatively large samples. No evidence of attraction of bats by turbines was found, either at individual turbines, or at the broader level of entire wind farms. Due to the lack of sites available for comparison, and the ground-positioning of recorders, this result does not provide strong evidence against bat attraction hypotheses.

Figure 23: Interaction plots for 2-way ANOVA of bat and bird pass rates vs. year and site. X axis is year: 0 = year before construction (2011), 1 = year after construction (2012). Y axis is log-transformed mean pass rate. Error bars are 95% confidence intervals. The solid red line is Oak Glen recorders (treatment location in the Before-After study) and the blue dotted line is all other recorders in the region (pseudo-control locations). Both year and treatment have a positive effect, however the increase in activity at Oak Glen is slightly less than the increase at control sites, suggesting that the increase at Oak Glen is not attributable to the construction of a wind farm.
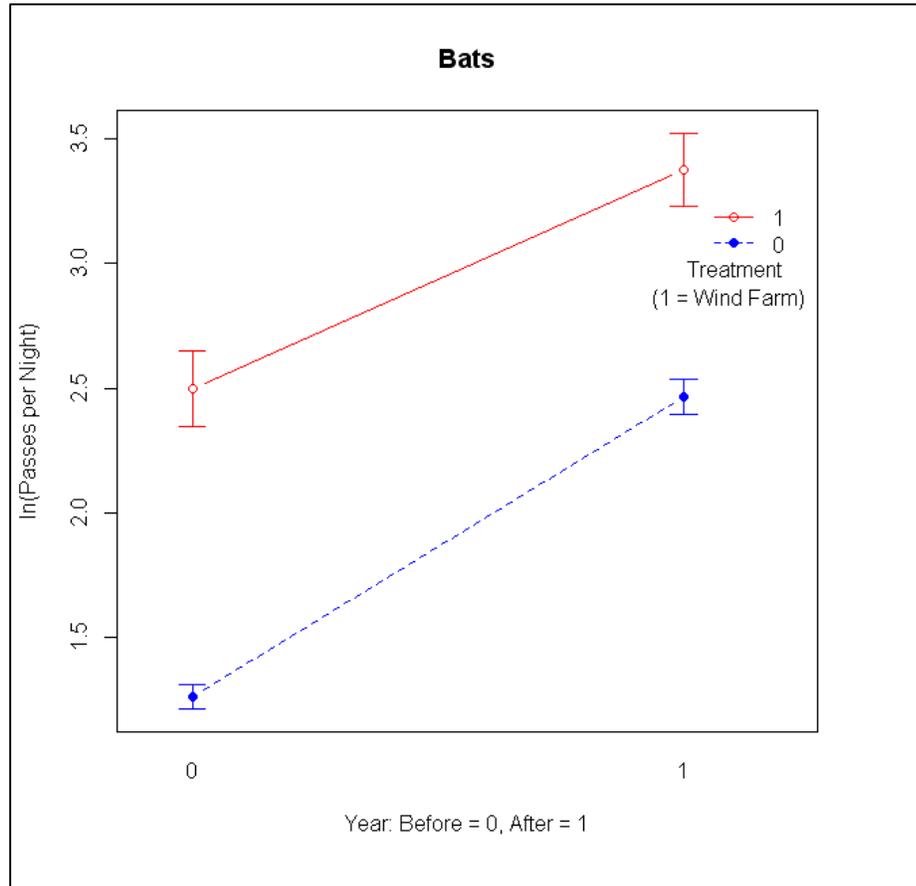
Figure 24: Mean nightly pass counts at before/after study locations, by species. A mixing of effects similar to that seen in Figure 23 is apparent. Both the treatment location (Oak Glen) and year after construction (2012) have higher pass rates for most species; however the effect of year at Oak glen is slightly less than the effect at the control locations. Error bars represent error associated only with the species identification process. They are 95% confidence intervals for the mean nightly pass rate under the assumption of accurate pass rate estimates for each site. They do not include the uncertainty associated with overall pass counts, which is displayed by the confidence intervals in Figure 23.
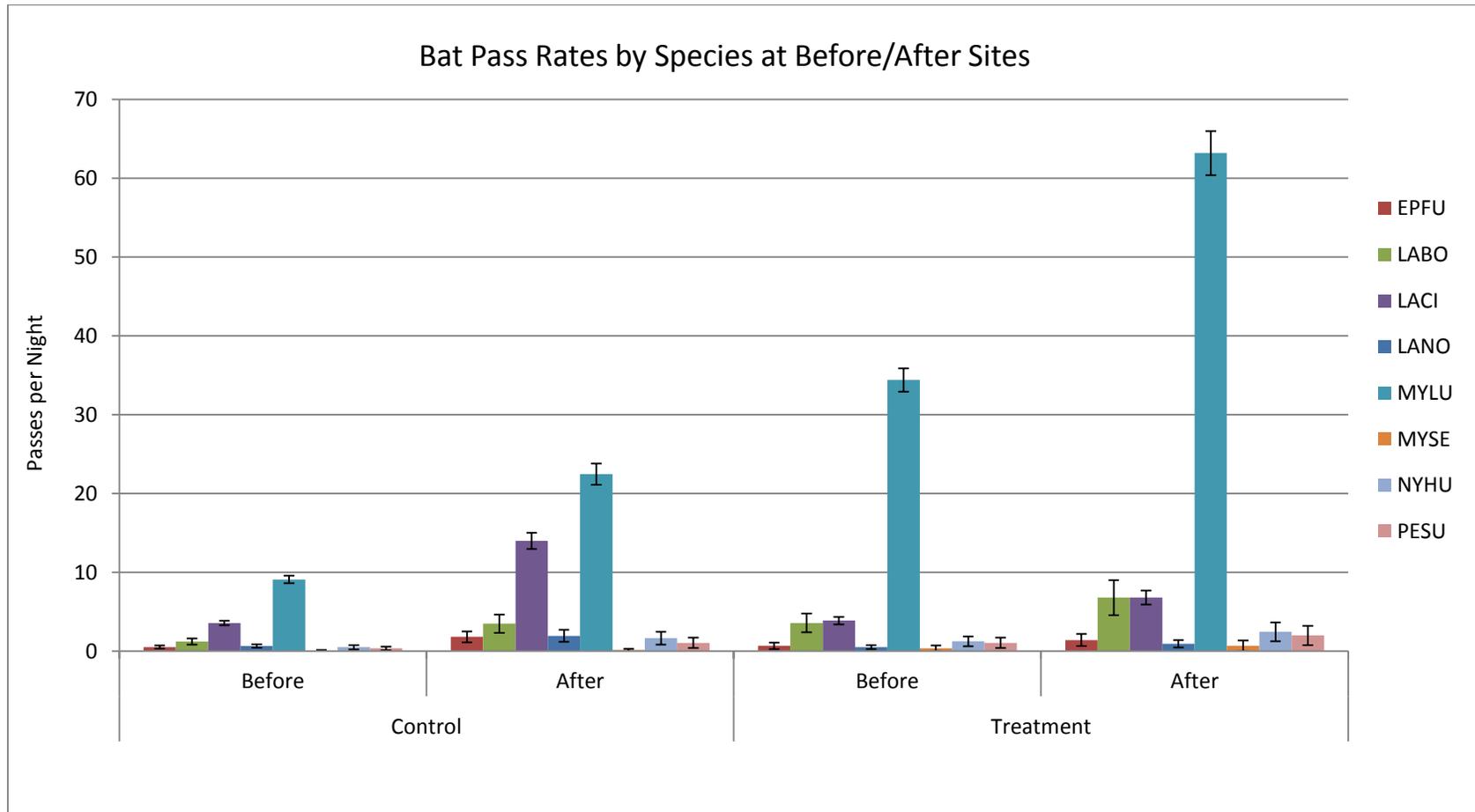
Figure 25: Interaction plot for 2-way ANOVA of bird pass rates at wind farm sites in Before-After study. A strong interaction between year and treatment was apparent here, suggesting that the construction of a wind farm at Oak Glen may have caused reduced bird activity at that site. However, this finding is based on a single treatment location with only one year of pre- and one year of post-construction monitoring.
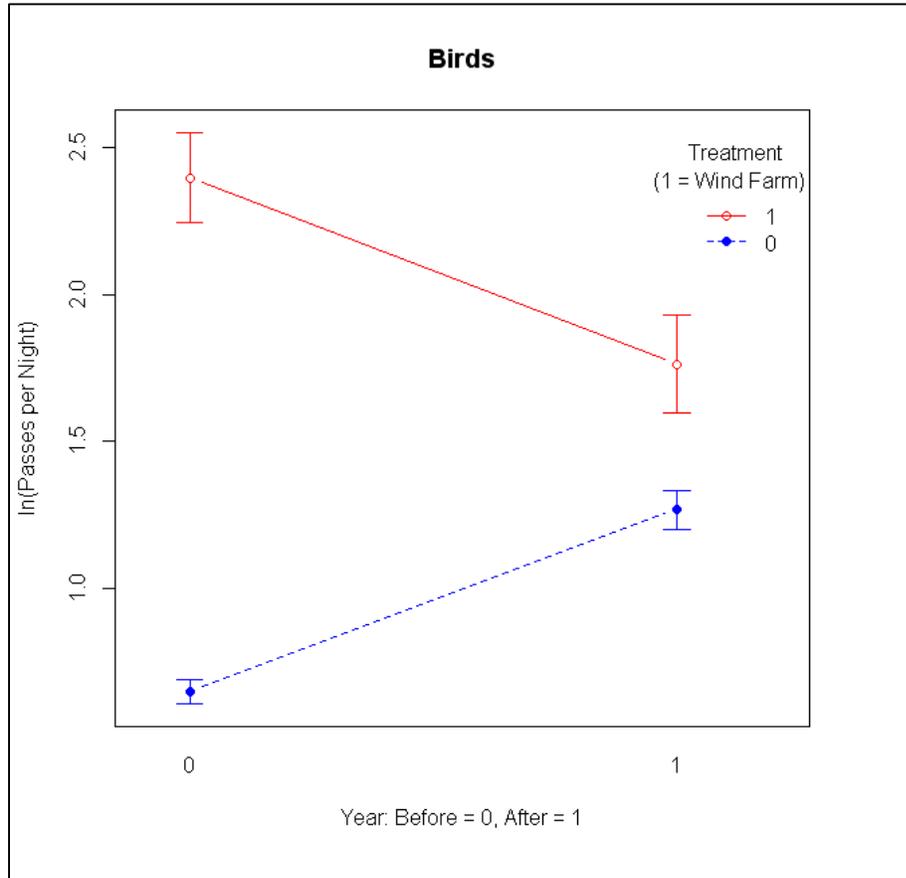
Figure 26: Bat pass site means at distance-to-turbine arrays within two wind farms, and 95% confidence intervals based on the variance in pass rates and the number of recording nights at each site. Recorders are grouped by turbine ID and location (wind farm).

Mean Nightly Bat Passes (all species) at Distance-to-Turbine Arrays
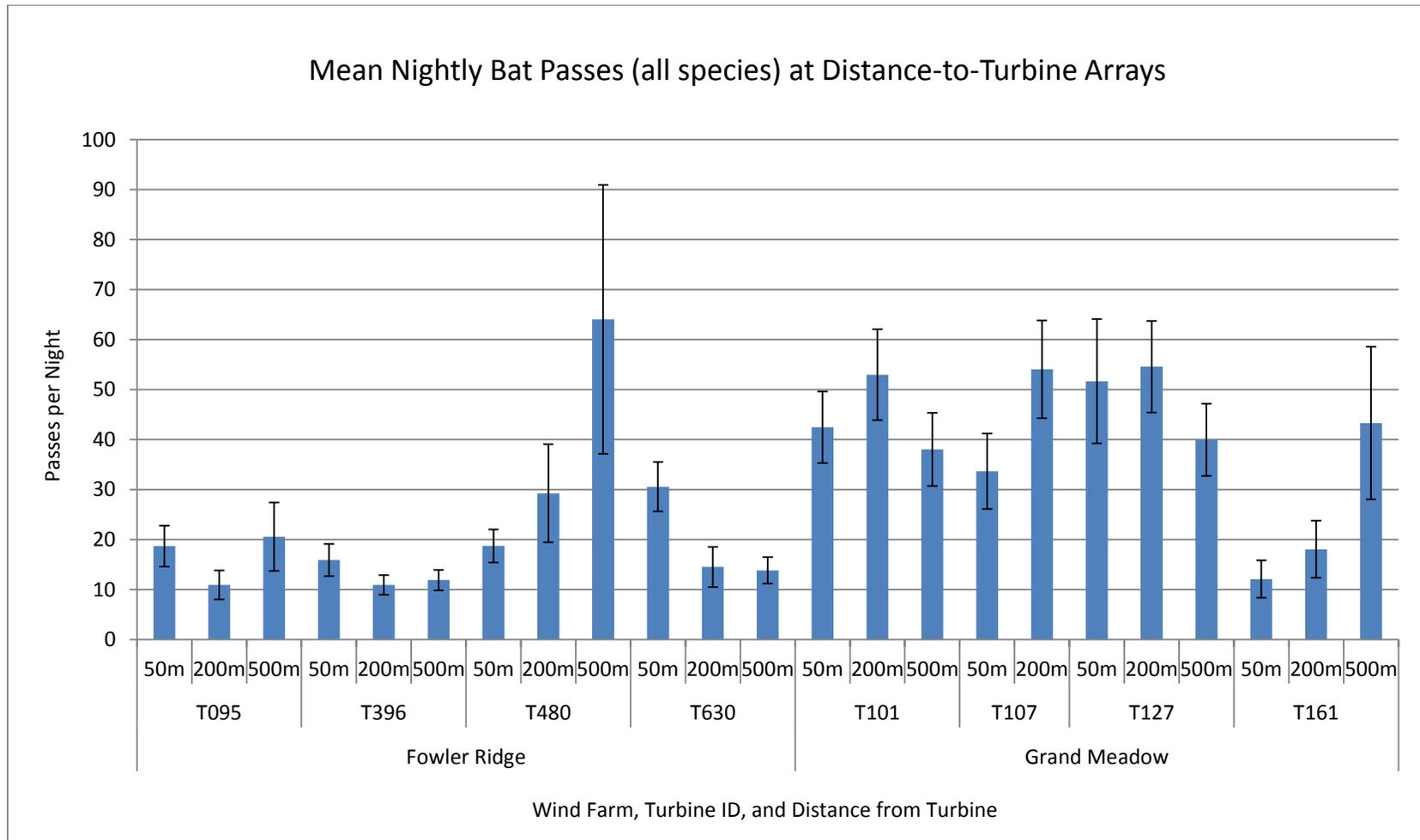
Figure 27: Change in mean over distance at distance-to-turbine arrays, listed by turbine ID. GM = Grand Meadow wind farm, FR = Fowler Ridge wind farm.
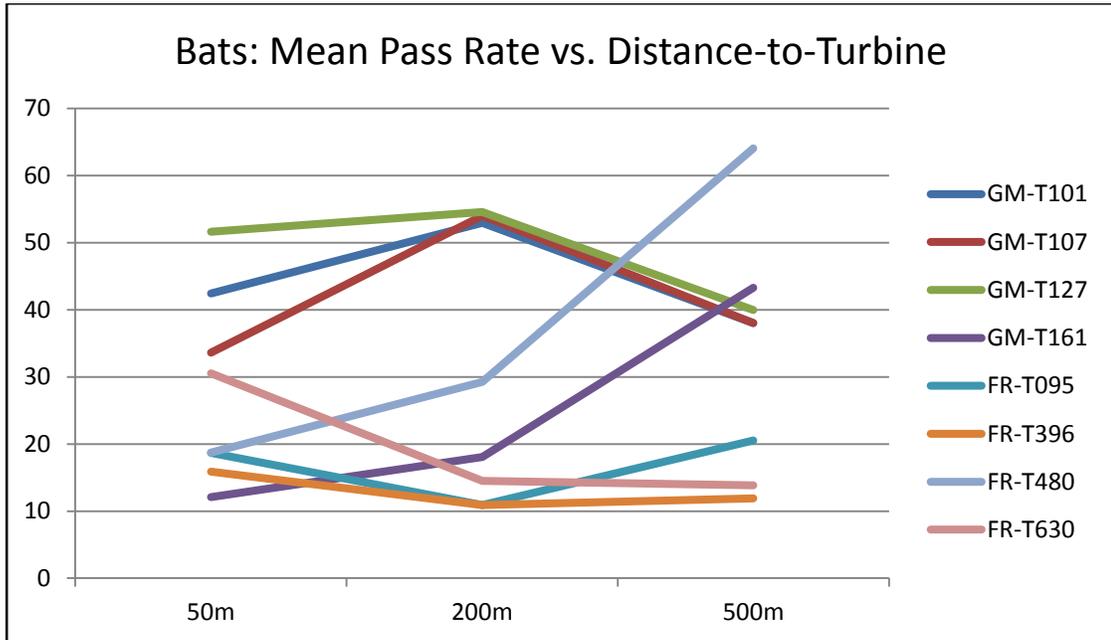
Figure 28: Bat pass rates at distance-to-turbine arrays at Grand Meadow wind farm, by species. Error bars represent error associated only with the species identification process. They are 95% confidence intervals for the mean nightly pass rate under the assumption of accurate pass rate estimates for each site. They do not include the uncertainty associated with overall pass counts, which is displayed by the confidence intervals in Figure 26.
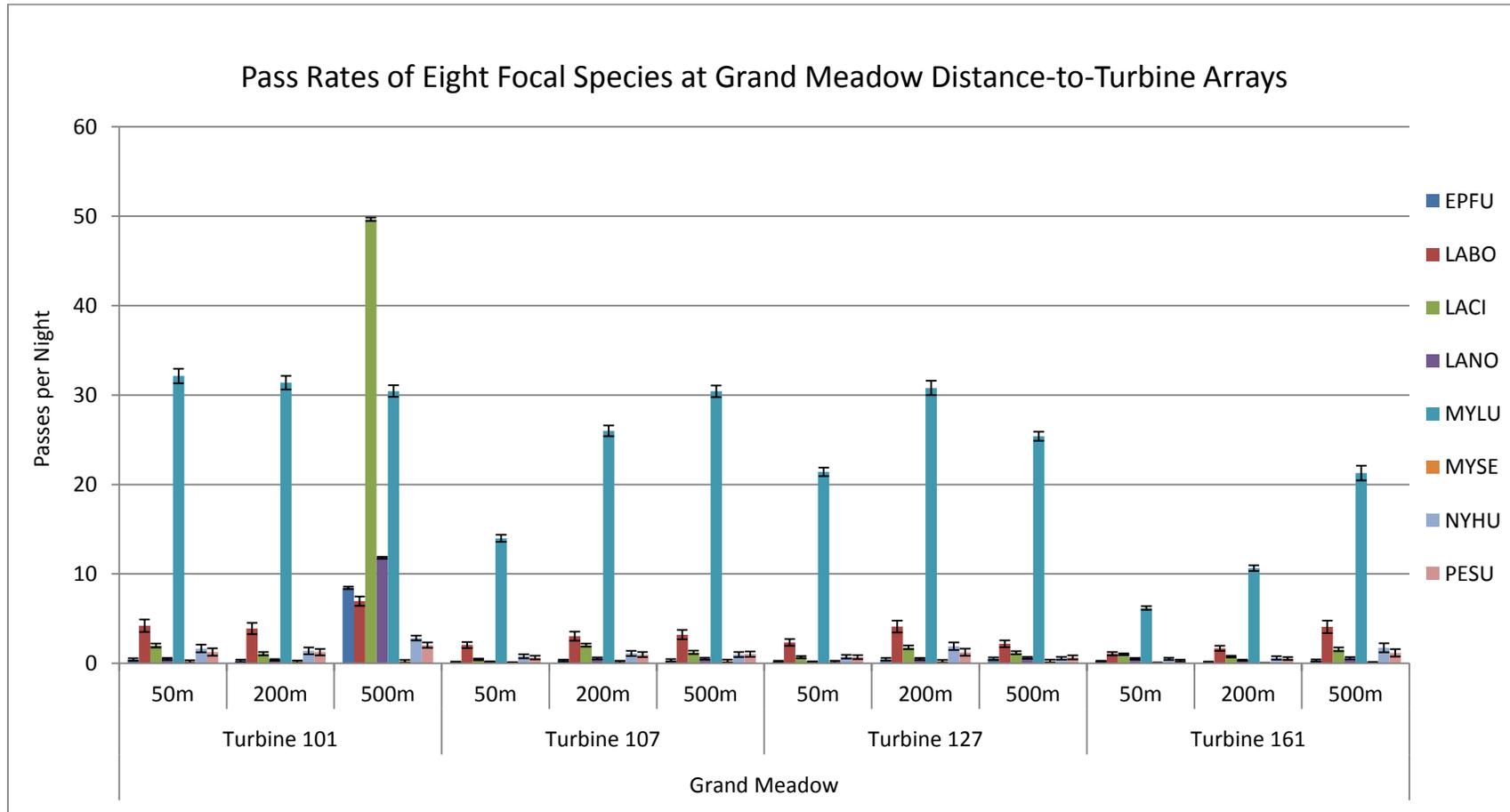
Figure 29: Bat pass rates at distance-to-turbine arrays at Fowler Ridge wind farm, by species Error bars represent error associated only with the species identification process. They are 95% confidence intervals for the mean nightly pass rate under the assumption of accurate pass rate estimates for each site. They do not include the uncertainty associated with overall pass counts, which is displayed by the confidence intervals in Figure 26.
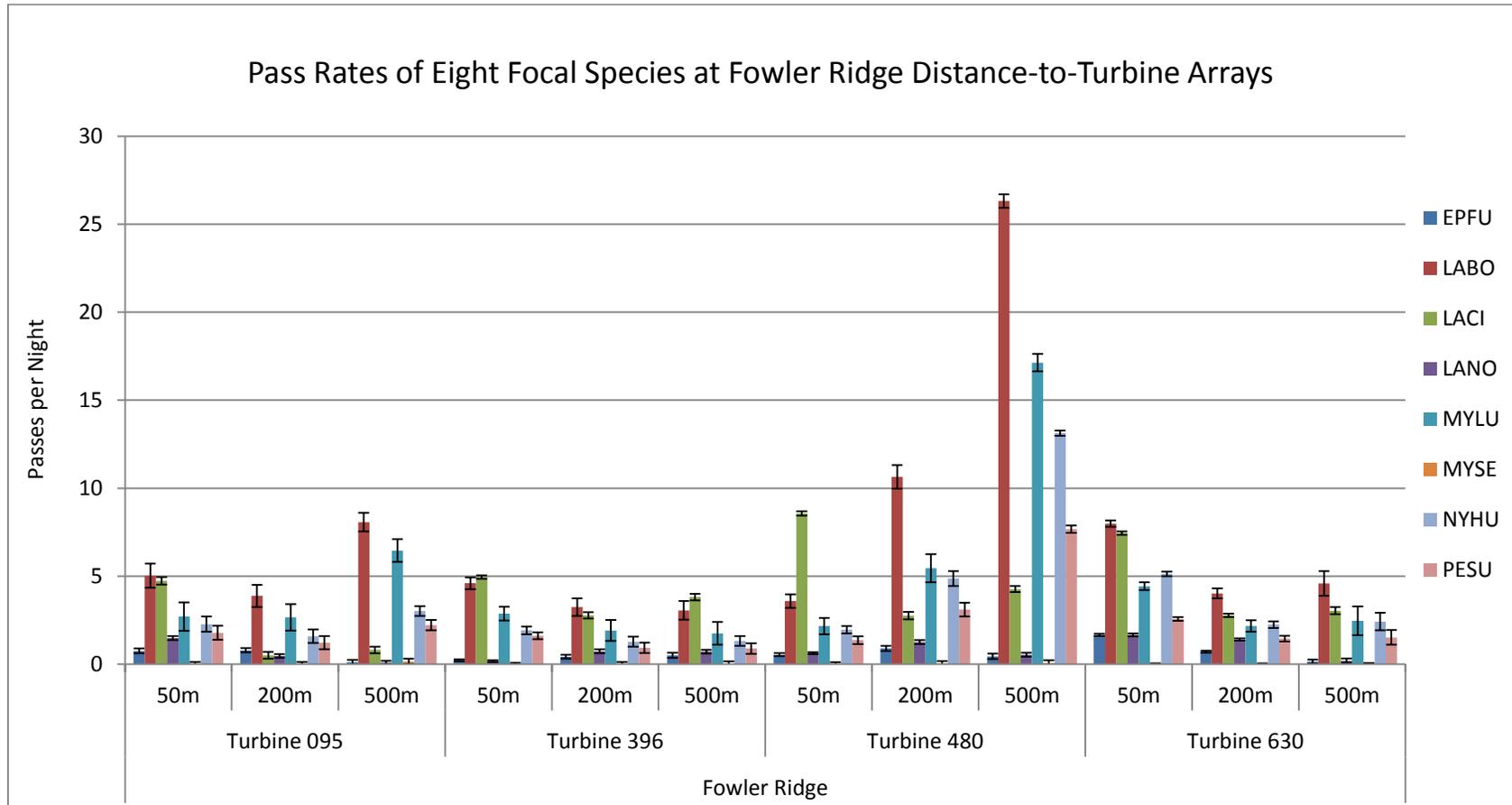
Figure 30: Bat pass rates of three migratory tree-roosting species among distance-to-turbine arrays at Grand Meadow and Fowler Ridge wind farms. Error bars represent error associated only with the species identification process. They are 95% confidence intervals for the mean nightly pass rate under the assumption of accurate pass rate estimates for each site. They do not include the uncertainty associated with overall pass counts, which is displayed by the confidence intervals in Figure 26.
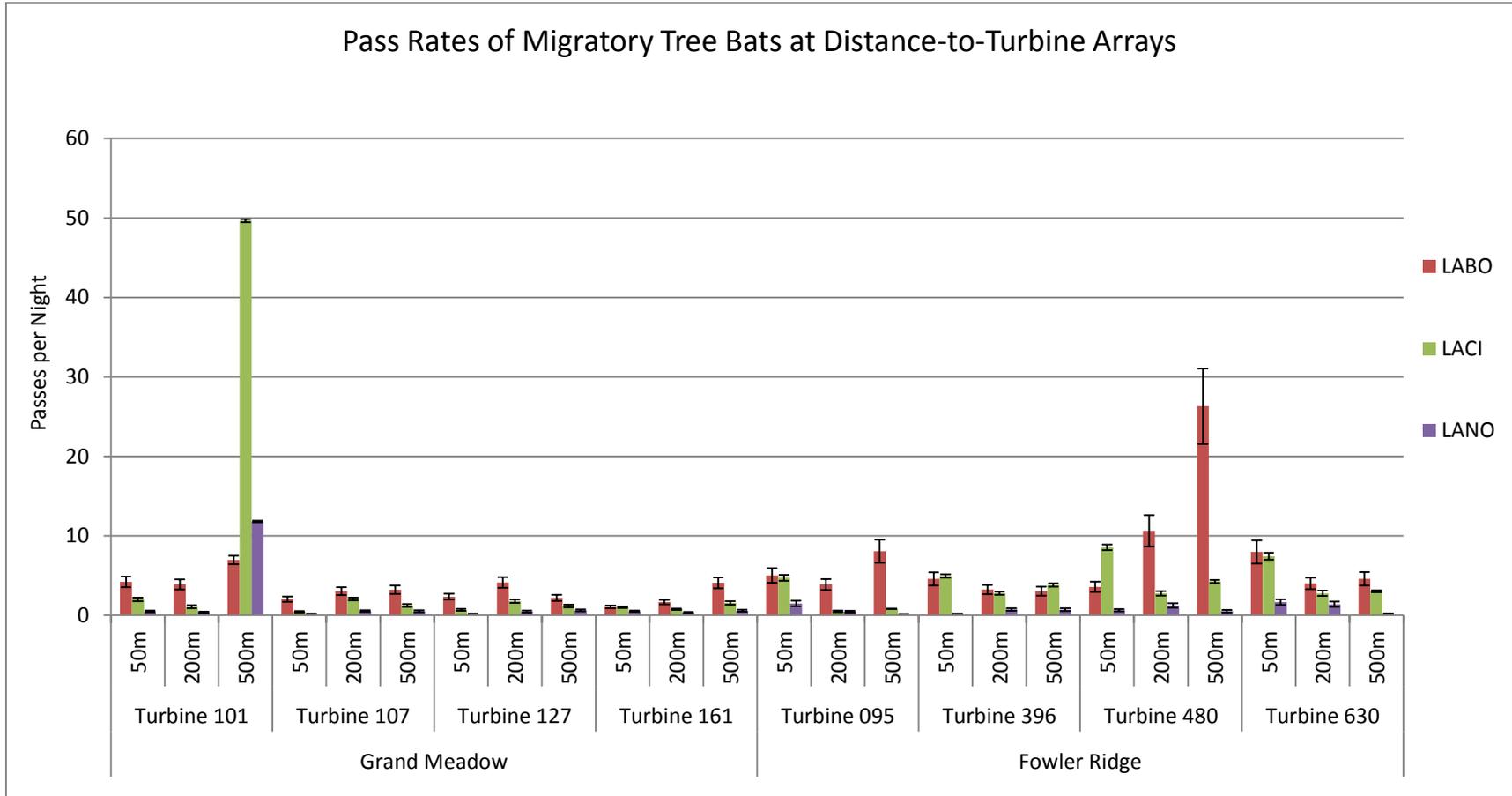
Figure 31: Plot of log-transformed bat (a) and bird (b) pass rates from all wind farm recorders vs. distance from turbine. Variance of log-transformed pass rates appears to decrease with distance from turbines. The number of recorders also decreases with distance, which might explain the lack of variation. No clear pattern of increasing or decreasing activity with distance is apparent.

(a)
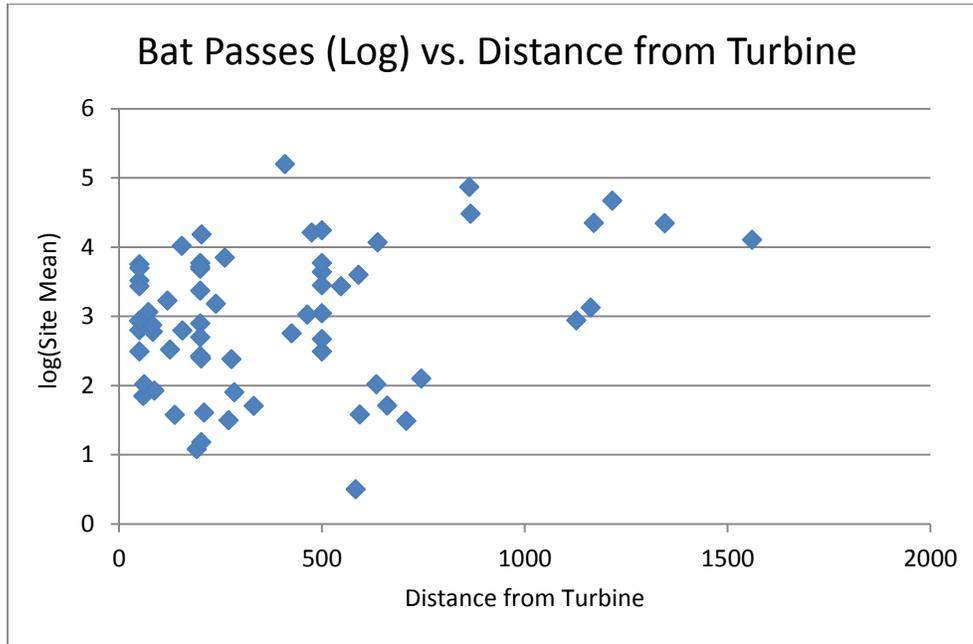
(b)
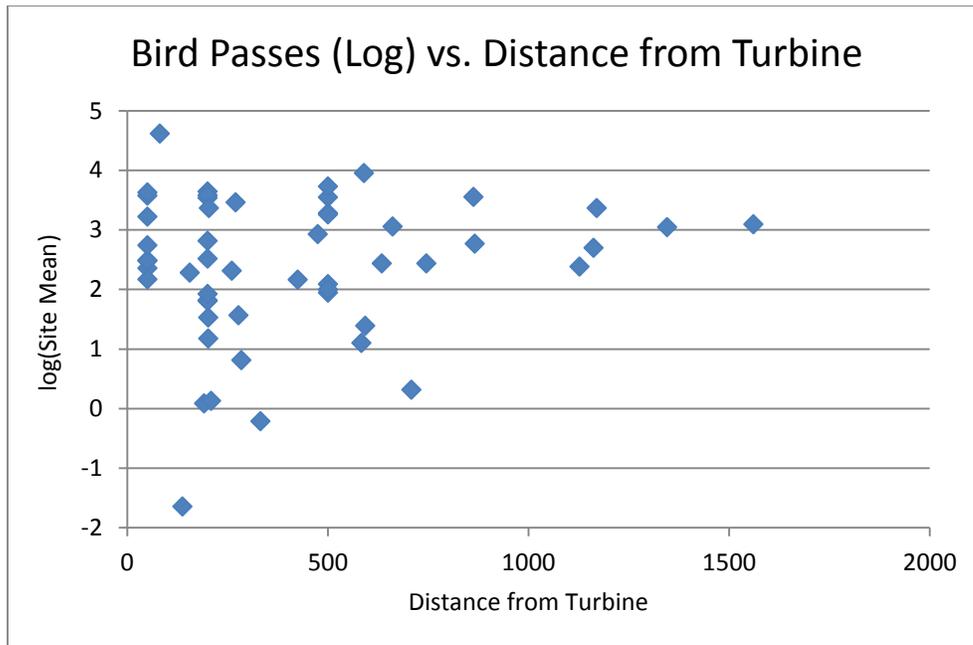
General Discussion

Using acoustic monitors, I was able to learn more about the activity patterns of bats than about the activity patterns of birds. Whereas differences in bat activity were evident at both fine and coarse scales, including huge differences among regions at the continental scale, acoustic monitors were not useful for detecting the differences that result in high bat fatality rates at some sites and low bat fatality rates at others. Some of the possible explanations for this are presented in the Chapter 1 discussion, but the critical missing element preventing the detection of a relationship between activity and fatalities may have been the third dimension, altitude. The fatality study was essentially an examination of activity patterns in two dimensions. Wind-wildlife researchers have struggled to find a reliable measure of activity that is useful for determining fatality impacts. Finding this measure may depend on first determining the altitudinal distribution of bats in migratory flight. If bats are attracted to turbines, they may descend from heights above the rotor-swept zone, in which case we may need to look for migratory corridors at heights greater than a few hundred meters. Current and future technologies may facilitate the study of bats and other migrants at these heights, and this may be an important area for future research.

Song Meter's dual microphone functionality had the advantage of collecting information on a wide variety of species, but in this project it functioned best as a bat detector. Bat calls were detected more frequent despite limited microphone reception range. Also, bat data were much easier to process and identify to species than bird data. The difference in species identification has a lot to do with the greater diversity of birds and their calls, as well as the fact that their vocalizations are within the frequency range of most other sources of noise (wind, rain, most insects, etc.). Special care has to be taken when designing a microphone system that will effectively block out external sounds but capture night flight calls (e.g., Graber 1959), but this was not logistically feasible with my approach of recording at many places simultaneously. The recorder was ideal for long-interval remote data collection on bats (and insects) at many sites. It was quick to configure and deploy, and with the exception of the microphones it was very robust in a wide range of field settings.

The bat data collected during this project is extensive, and will contribute to our growing knowledge of microchiroptera, both within wind-wildlife research and in the field of bat ecology more generally. It may have been suspected that bats prefer forested edges in agricultural settings, but this project helped quantify that effect in terms of activity levels and the distance over which activity drops to baseline levels. The geographic extent of this study allowed for a quantification of the magnitude of differences in bat activity observable at the continental scale. Measurements of bat activity at any location are likely the product of a variety of factors at multiple scales, and local habitat and landscape effects should be viewed within a wider context of regional patterns.

The program Kaleidoscope worked well with large data sets, processing hundreds of thousands of calls quickly and producing straightforward output. Since we had manually assured that each file contained bat passes (phase 1 of data processing) before using the program, I had the ability to assess not only accuracy, but detection rates as well. Detection rates were low, especially using Accurate mode. While that might be expected and preferred if higher certainty is needed (e.g., trying to establish presence/absence of a rare species), the low detection rates using Sensitive mode were surprising. This was a major problem for this study, and would be an even more severe problem with a dataset that had not been pre-analyzed, because Kaleidoscope does not identify passes consistently across species or geographic regions with differing species compositions. This is partly a result of the current state of call identification software, which is a relatively new and rapidly developing field (Britzke et al. 2013), and partly a result of the diversity of bat calls. For example, Kaleidoscope over-identifies passes as eastern red bats (classifies many calls that are not eastern red bats as eastern red bats) because that species has a very sporadic call pattern that varies dramatically in frequency, which means it produces some calls that are very similar to calls of other species. This can be accounted for in visual identification by panning out and assessing the cadence and overall consistency among series of calls, a process that may be difficult to replicate in a computer program.

Because I had a large set of testing data to verify Kaleidoscope's performance within various groupings, I believe that I had a good understanding of how it performs, and was able to produce estimates for the eight focal species that probably were relatively accurate. Unidentified calls will be a problem associated with the use of any automated species identification process, and manual identification should always be used for calibration of both accuracy and detection.

Dealing with zeros in the data was an issue throughout the analysis for this project, however a log transformation (in the case of individual nightly pass counts, log of pass count plus one was used) seemed to address it adequately for most analyses. Other approaches such a zero-inflated Poisson or zero-inflated negative binomial models might have worked as well if pass counts were not as heavily skewed, but logs were a simple transformation that allowed results to be easily translated and interpreted. I preferred simpler statistical approaches in general, due to the complexity of the dataset itself, which can be categorized by many temporal and spatial attributes, as well as by recorder groupings such as location or distance category, and by taxon (bats, bat species, or birds).

The lack of relationship between pass rates and fatalities was discouraging, but it also raises some important questions about bat movement and fatalities. My findings might suggest that turbines do not kill local bats but rather transient migrating bats. Migrating bats might be in greater need of an easily-accessible roost at the end of a long migration flight, and may be willing to examine the largest vertical tree-like object on the landscape, as suggested by Cryan and Barclay (2009). There is a counterargument that turbines are not trees, but neither are bridges, farmhouses, or numerous other types of anthropogenic structures that bats have used for shelter. The common use of a wide range of unnatural roosts by bats suggests that bats are relatively inquisitive by nature, which might cause them to inspect unfamiliar objects and result in unfortunate consequences when encountering a wind farm.

Elevated activity in the Great Lakes region was the most significant finding of this project and suggests that extra caution should be taken prior to wind development in that area. Even though I accounted for some effects of local landscape features when modeling the effect of region, it is unclear exactly how much of an effect recorder placement had on the difference in activity between the Great Lakes and inland sites. Many inland sites were selected specifically to avoid confounding factors such as trees, water, or buildings in order to address questions about local activity patterns. Placement of many of the Great Lakes recorders did not, or could not, avoid such features. There were two reasons for this: 1) most Great Lakes sites were not associated with a study that required the placement of recorders at a certain distance from a particular feature, and 2) grassland and open field sites are simply less available closer to the Lakes. For instance, it's difficult to place a recorder in relative proximity to the coast anywhere on the Door Peninsula or Upper Peninsula without it being near trees or water. While that complicates the interpretation of

results from regional comparisons and models, it also indicates something about habitat density in those areas, which might make them preferable for bats and potentially risky for wind power.

Effects found in Chapter 3 should be interpreted cautiously due to small before/after group sample size. The avoidance of wind farms by birds was based on a single pre-construction year and a single post-construction year at only one treatment location. Before acting on any conclusions provided here, these results should be replicated. Also, findings of no effects in the distance-to-turbine study do not necessarily indicate a lack of attraction to turbines by bats. The limited duration and sample size of the distance-to-turbine arrays, and ground placement of recorders meant that bat attraction may have gone undetected. Results of the fatality analysis suggest that I was not observing a substantial portion of the bats that were at risk of turbine collisions, which may be the same bats affected by attraction. More study of this phenomenon using alternate methods may be able to either confirm or deny the attraction hypothesis.

Pass rates are an imperfect index of bat activity (Kunz et al. 2007b), and many factors can bias activity estimates based on acoustic data. Acoustic detection rates are likely to be inconsistent among bat species due to differences in microphone reception range for varying call frequencies and distinct vocalizations. Also, the triggering mechanism I used allows one bat to create multiple pass files by flying in and out of a recorder's range of acoustic detection. Single bats creating many pass files elevate pass rates, but that may be appropriate for the questions I posed. In the context of assessing risk from wind turbines, elevated pass rates may accurately indicate increased exposure to collisions by registering higher activity, even of one individual, within the area. Conversely, multiple bats flying or swarming within the recorder's range will only register a single pass file. However, pass files with multiple bats or continuous calling were relatively rare and occurred more frequently at high-activity sites. This has the effect of moderating pass rates at those high-activity locations.

Further, activity rates measured at ground-level may not be an accurate indicator of risk from wind turbines. Both activity levels and species composition can differ greatly between the ground and the rotor-swept zone (Kunz et al. 2007b, Baerwald and Barclay 2009). The main advantage of ground-based recording was easy deployment and access to more locations. Such placement allowed data to be collected from sites without structures such as meteorological towers or turbines, and facilitated sampling from a wide range of geographical and ecological

settings. While not ideal for predicting fatality rates, this diversity of recording sites led to the important findings regarding local and regional activity patterns in Chapter 2.

Our understanding of bat migration and use of airspace throughout the year remains limited. Studying movements of small, nocturnal flying mammals is challenging, but this and other studies have demonstrated that acoustic monitoring can be a useful tool for such a purpose. These findings provide some quantification of variation in bat activity at multiple geographic scales, and in bird activity at a coarse geographic scale. Results indicating consistently high activity levels in certain regions, the Great Lakes in particular, may alert us to potential risks to bats and birds from wind energy development.

General Conclusions

Bat migration is poorly understood, but knowledge of the migratory patterns of bats is likely critical for safe development of wind energy. This project has uncovered some patterns associated with bat activity at the local level, and some effects of habitat features, but most importantly it has put the magnitude of differences in bat activity levels among geographic regions into perspective. Increases in activity from southwestern Minnesota, through Minnesota and Wisconsin to central and northern Lake Michigan span three orders of magnitude, and may give us a frame of reference to begin understanding variation in bat activity at the continental scale, and begin recognizing broadly-defined migratory corridors. Clearly, Great Lakes coasts are areas of intense activity during migration seasons, for both bats and birds.

It is unlikely that bat fatality rates can be predicted with the method of ground-based acoustic detection used in this project. Activity levels recorded at fatality sites were all in the low to medium range within the context of the entire research project. As such, results from the fatality study are not applicable to high-activity sites. The failure to find a relationship between activity and fatality rates does not indicate that the relationship does not exist, nor that sites with elevated activity such as Great Lakes coasts do not warrant a high degree of precaution when under consideration for wind energy development.

Bat activity likely depends on a suite of many factors, only a few of which I addressed in this project. In addition to geographic region, I found that bat activity varies with distance to trees and distance to water, and that activity spikes within 200 m of the edge of forest corridors in agricultural settings. Differences in bird activity were apparent only at the coarsest geographic scale. Most of the fine-scale patterns observed with bats were not evident with birds.

After two decades of wind-wildlife research, reliable methods for evaluating collision impact risks at prospective wind energy sites remain elusive. Development of risk assessment methods should focus on first answering the difficult questions regarding bat migration, such as 1) what technologies can be used to measure the altitudinal distribution of migrating bats, and 2) how do we track or observe bat migration corridors in three dimensions. Answering these questions may rely on the development of high-tech solutions; however, promising approaches involving fewer logistical and technological challenges should be pursued as well. I found that simple variables

such as geographic region and Ecoregion are useful predictors of bat activity levels. The most consistency in activity levels for the entire research project was observed within large-scale geographic regions. Additional research into the relationship between fatalities and high-level spatial variables (e.g., the regional analysis in Arnett and Baerwald 2013) could be very effective and require limited resources.

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Appendix A

Recorder locations, objectives, regions, and recording seasons. WF = wind farm. Recording seasons: S = spring, A = autumn. Active recording seasons for a site are indicated by an x. See below table for Primary Objective and Region classifications.

| | | | | Coordinates | | Regions | | | | Recording Seasons | | | | | |
| | | | | | | | | | | 2010 | | 2011 | | 2012 | |
ID	Site	Location	Primary Objective	Long	Lat	3Reg	10 Reg	15Reg	IsGL	S	A	S	A	S	A
1	B1	Barton WF	WF	-93.0710	43.4153	Middle	MS	I	0	x	x	x	x	x	
2	B2	Barton WF	WF	-93.1263	43.4155	Middle	MS	I	0	x	x	x	x	x	
3	B3	Barton WF	WF	-93.1042	43.3691	Middle	MS	I	0	x	x	x	x	x	
130	BAILEY	BAILEY	LS-GL	-87.0528	45.1044	GL	LM	B	1				x	x	x
146	Batman1_F11	Batman1_F11	LS-GL	-82.7269	43.9540	GL	LH	E	1				x		
147	Batman1_F12	Batman1_F12	LS-GL	-86.5712	45.7419	GL	LM	A	1						x
148	Batman1_S12	Batman1_S12	LS-GL	-82.4379	41.3815	GL	LE	F	1					x	
149	BATMAN1-KUHL	BATMAN1-KUHL	LS-GL	-83.3952	43.8008	GL	LH	E	1						x
150	Batman2_F11	Batman2_F11	LS-GL	-82.7688	43.9532	GL	LH	E	1				x		
151	Batman2_F12	Batman2_F12	LS-GL	-86.6108	45.7391	GL	LM	A	1						x
152	Batman2_Kuhl_F12	Batman2_Kuhl_F12	LS-GL	-83.4116	43.7977	GL	LH	E	1						x
153	Batman2_S12	Batman2_S12	LS-GL	-82.4363	41.3746	GL	LE	F	1					x	
106	BELGIUM	BELGIUM	LS-GL	-87.8435	43.5140	GL	LM	C	1				x	x	x
136	BETSIE	BETSIE	LS-GL	-86.2545	44.6913	GL	LM	D	1				x	x	
98	BLUE1	Blue Sky WF	WF	-88.3020	43.9068	Middle	WE	H	0				x	x	x
99	BLUE2	Blue Sky WF	WF	-88.2770	43.8476	Middle	WE	H	0				x	x	x
100	BLUE3	Blue Sky WF	WF	-88.2439	43.8921	Middle	WE	H	0				x	x	x
101	BLUE4	Blue Sky WF	WF	-88.2356	43.8727	Middle	WE	H	0				x	x	x
36	BM1500	Blue Mounds	LS-GR	-96.2397	43.6964	SW	SW	L	0	x	x	x	x		
37	BM200	Blue Mounds	LS-GR	-96.2192	43.7034	SW	SW	L	0			x	x		

38	BM500	Blue Mounds	LS-GR	-96.2274	43.6963	SW	SW	L	0	x	x	x	x		
39	BM5K	Blue Mounds	LS-GR	-96.3021	43.7028	SW	SW	L	0	x	x				
40	BMR	Blue Mounds	LS-GR	-96.2112	43.6986	SW	SW	L	0	x	x	x	x		
107	BRUEM	BRUEM	LS-GR	-87.5504	44.4594	GL	LM	C	1				x	x	x
41	BUFF1	Buffalo Ridge WF	WF	-96.1657	44.1626	SW	SW	L	0			x	x	x	x
42	BUFF2	Buffalo Ridge WF	WF	-96.1491	44.1532	SW	SW	L	0			x	x	x	x
43	BUFF3	Buffalo Ridge WF	WF	-96.0438	44.1333	SW	SW	L	0			x	x	x	x
44	BUFF4	Buffalo Ridge WF	WF	-96.0841	44.1013	SW	SW	L	0			x	x	x	x
154	CEDAR	CEDAR	LS-GL	-83.3056	41.6875	GL	LE	F	1				x	x	
102	CEDAR1	Cedar Ridge WF	WF	-88.2859	43.7338	Middle	WE	H	0			x	x	x	x
103	CEDAR2	Cedar Ridge WF	WF	-88.2956	43.7180	Middle	WE	H	0			x	x	x	x
104	CEDAR3	Cedar Ridge WF	WF	-88.3208	43.7209	Middle	WE	H	0			x	x	x	x
105	CEDAR4	Cedar Ridge WF	WF	-88.3306	43.6994	Middle	WE	H	0			x	x	x	x
155	ERIE-E	ERIE-E	LS-GL	-80.3794	42.0150	GL	LE	F	1					x	
156	ERIE-W	ERIE-W	LS-GL	-82.5065	41.3788	GL	LE	F	1					x	
157	EVANGOLA	EVANGOLA	LS-GL	-79.1013	42.6075	GL	LE	F	1				x	x	
142	FISH	FISH	LS-GL	-83.5085	43.6970	GL	LM	E	1						x
108	FOREST	Forest Array	LS-GL	-87.8108	43.4621	GL	LM	C	1				x	x	x
109	FOREST-10KM	Forest Array	LS-GL	-88.0232	43.4395	GL	LM	C	1				x	x	x
110	FOREST-6KM	Forest Array	LS-GL	-87.9416	43.4743	GL	LM	C	1				x	x	x
132	GARDEN1	GARDEN1	LS-GL	-86.6660	45.7160	GL	LM	A	1					x	x
133	GARDEN2	GARDEN2	LS-GL	-86.5360	45.7469	GL	LM	A	1					x	x
163	GL-RPLC1 (PB)	Point Beach Array	LS-GL	-87.5218	44.2045	GL	LM	C	1					x	x
4	GM101A	Grand Meadow WF	DTT	-92.6345	43.7415	Middle	MS	I	0						x
5	GM101B	Grand Meadow WF	DTT	-92.6345	43.7402	Middle	MS	I	0						x
6	GM101C	Grand Meadow WF	DTT	-92.6298	43.7395	Middle	MS	I	0						x
7	GM107A	Grand Meadow WF	DTT	-92.6346	43.7361	Middle	MS	I	0						x

8	GM107B	Grand Meadow WF	DTT	-92.6346	43.7375	Middle	MS	I	0						x
9	GM127A	Grand Meadow WF	DTT	-92.6940	43.6955	Middle	MS	I	0						x
10	GM127B	Grand Meadow WF	DTT	-92.6919	43.6955	Middle	MS	I	0						x
11	GM127C	Grand Meadow WF	DTT	-92.6896	43.6930	Middle	MS	I	0						x
12	GM161A	Grand Meadow WF	DTT	-92.6668	43.6729	Middle	MS	I	0						x
13	GM161B	Grand Meadow WF	DTT	-92.6694	43.6729	Middle	MS	I	0						x
14	GM161C	Grand Meadow WF	DTT	-92.6694	43.6775	Middle	MS	I	0						x
137	HOLLAND	HOLLAND	LS-GL	-86.2080	42.7752	GL	LM	D	1				x	x	
78	IN095A	Fowler Ridge WF	DTT	-87.4578	40.5911	Middle	EA	M	0						x
79	IN095B	Fowler Ridge WF	DTT	-87.4557	40.5911	Middle	EA	M	0						x
80	IN095C	Fowler Ridge WF	DTT	-87.4552	40.5928	Middle	EA	M	0						x
81	IN396A	Fowler Ridge WF	DTT	-87.2531	40.5970	Middle	EA	M	0						x
82	IN396B	Fowler Ridge WF	DTT	-87.2518	40.5988	Middle	EA	M	0						x
83	IN396C	Fowler Ridge WF	DTT	-87.2477	40.5988	Middle	EA	M	0						x
84	IN480A	Fowler Ridge WF	DTT	-87.2126	40.6242	Middle	EA	M	0						x
85	IN480B	Fowler Ridge WF	DTT	-87.2100	40.6246	Middle	EA	M	0						x
86	IN480C	Fowler Ridge WF	DTT	-87.2097	40.6207	Middle	EA	M	0						x
87	IN630A	Fowler Ridge WF	DTT	-87.2737	40.5612	Middle	EA	M	0						x
88	IN630B	Fowler Ridge WF	DTT	-87.2756	40.5612	Middle	EA	M	0						x
89	IN630C	Fowler Ridge WF	DTT	-87.2676	40.5625	Middle	EA	M	0						x
23	J1500	Jackson Array	LS-FC	-95.0149	43.7254	Middle	MS	J	0	x	x	x	x		
24	J200	Jackson Array	LS-FC	-95.0346	43.7190	Middle	MS	J	0			x	x		
25	J500	Jackson Array	LS-FC	-95.0279	43.7182	Middle	MS	J	0	x	x	x	x		
26	J500-F2011	Jackson Array	LS-FC	-95.0279	43.7182	Middle	MS	J	0	x	x	x	x		
27	J5K	Jackson Array	LS-FC	-94.9725	43.7287	Middle	MS	J	0	x	x				
28	J5K-2	Jackson Array	LS-FC	-94.9725	43.7287	Middle	MS	J	0	x	x	x	x		
29	J5-X-JR	Jackson Array	LS-FC	-95.0372	43.7165	Middle	MS	J	0	x	x	x	x		

30	JR	Jackson Array	LS-FC	-95.0372	43.7165	Middle	MS	J	0	x	x	x	x		
111	KEWA	Kewaunee Array	LS-GL	-87.4951	44.4644	GL	LM	C	1				x	x	x
112	KEWA-10KM	Kewaunee Array	LS-GL	-87.7683	44.4580	GL	LM	C	1					x	x
113	KEWA-6KM	Kewaunee Array	LS-GL	-87.6385	44.4741	GL	LM	C	1					x	x
114	LSSP	LSSP	LS-GL	-87.8951	43.0313	GL	LM	C	1				x	x	
31	M1500	Martin Array	LS-FC	-94.3405	43.5863	Middle	MS	J	0	x	x	x	x		
32	M200	Martin Array	LS-FC	-94.3569	43.5761	Middle	MS	J	0			x	x		
33	M500	Martin Array	LS-FC	-94.3529	43.5763	Middle	MS	J	0	x	x	x	x		
34	M5K	Martin Array	LS-FC	-94.2953	43.5749	Middle	MS	J	0	x	x				
115	MAY	MAY	LS-GL	-87.7564	43.7803	GL	LM	C	1				x		
138	MEARS	MEARS	LS-GL	-86.4365	43.7838	GL	LM	D	1				x	x	
35	MR	Martin Array	LS-FC	-94.3591	43.5760	Middle	MS	J	0	x	x	x	x		
131	MUD	MUD	LS-GL	-87.1077	45.1164	GL	LM	B	1				x		
139	MUSK	MUSK	LS-GL	-86.3326	43.2358	GL	LM	D	1				x	x	
140	NORTH	NORTH	LS-GL	-86.2527	43.0834	GL	LM	D	1				x	x	
15	OAK1	Oak Glen WF	BA	-93.1056	43.9346	Middle	MS	I	0			x	x	x	x
16	OAK2	Oak Glen WF	BA	-93.1508	43.9191	Middle	MS	I	0			x	x	x	x
17	OAK3	Oak Glen WF	BA	-93.1556	43.9030	Middle	MS	I	0			x	x	x	x
18	OAK4	Oak Glen WF	BA	-93.1252	43.8993	Middle	MS	I	0			x	x	x	x
141	ORCHARD	ORCHARD	LS-GL	-86.3172	44.2791	GL	LM	D	1				x	x	
90	PA1	Casselman WF	WF	-79.1388	39.8434	Middle	EA	N	0				x		
91	PA2	Casselman WF	WF	-79.1379	39.8505	Middle	EA	N	0				x		
92	PA3	Casselman WF	WF	-79.1432	39.8565	Middle	EA	N	0				x		
93	PA4	Casselman WF	WF	-79.1437	39.8653	Middle	EA	N	0				x		
94	PA5	Casselman WF	WF	-79.1436	39.8716	Middle	EA	N	0				x		
95	PA6	Casselman WF	WF	-79.1123	39.8584	Middle	EA	N	0				x		
96	PA7	Casselman WF	WF	-79.0998	39.8677	Middle	EA	N	0				x		

97	PA8	Casselman WF	WF	-79.0965	39.8701	Middle	EA	N	0				x	
121	PB	Point Beach Array	LS-GL	-87.5190	44.2412		LM	C	1			x	x	x
118	PB10m_F12	Point Beach Array	LS-GL	-87.7164	44.2825	GL	LM	C	1				x	x
119	PB2_2010	Point Beach Array	LS-GL	-87.5330	44.2534	GL	LM	C	1			x		
120	PB3_2010	Point Beach Array	LS-GL	-87.5121	44.2117	GL	LM	C	1			x		
123	PB-3m	Point Beach Array	LS-GL	-87.6019	44.2663	GL	LM	C	1				x	x
124	PB4_2010	Point Beach Array	LS-GL	-87.5195	44.2108	GL	LM	C	1			x		
125	PB6m_F12	Point Beach Array	LS-GL	-87.6603	44.2819	GL	LM	C	1				x	x
71	PSCAL2	Penascal WF	WF	-97.4604	27.1300	Middle	TX	P	0				x	
72	PSCAL3	Penascal WF	WF	-97.5284	27.1025	Middle	TX	P	0				x	
73	PSCAL4	Penascal WF	WF	-97.5238	27.0844	Middle	TX	P	0				x	
74	PSCAL5	Penascal WF	WF	-97.5179	27.0323	Middle	TX	P	0				x	
75	PSCAL6	Penascal WF	WF	-97.4993	27.0215	Middle	TX	P	0				x	
76	PSCAL7	Penascal WF	WF	-97.5079	27.0149	Middle	TX	P	0				x	
77	PSCAL8	Penascal WF	WF	-97.5664	27.1478	Middle	TX	P	0				x	
126	Pt Bch IN_F11	Point Beach Array	LS-GL	-87.6019	44.2663	GL	LM	C	1				x	
117	Pt Bch_F11	Point Beach Array	LS-GL	-87.5218	44.2045		LM	C	1				x	
169	Pt Bch_F12	Point Beach Array	LS-GL	-87.5190	44.2413	GL	LM	C	1					x
55	PV1	Paynesville	BA	-94.7629	45.4131	Middle	MC	K	0	x	x	x	x	x
56	PV2	Paynesville	BA	-94.7037	45.4560	Middle	MC	K	0	x	x	x	x	x
57	PV3	Paynesville	BA	-94.7431	45.4723	Middle	MC	K	0	x	x	x	x	x
58	PV4	Paynesville	BA	-94.7433	45.4481	Middle	MC	K	0	x	x	x	x	x
59	PV5	Paynesville	BA	-94.7641	45.4143	Middle	MC	K	0				x	x
60	PV6	Paynesville	BA	-94.7644	45.4130	Middle	MC	K	0				x	x
61	PV7	Paynesville	BA	-94.7633	45.4211	Middle	MC	K	0				x	x
62	PV8	Paynesville	BA	-94.7626	45.4268	Middle	MC	K	0				x	x
158	Robin1_F11	Robin1_F11	LS-GL	-86.5232	43.6166	GL	LM	F	1				x	

170	Robin1_F12	Robin1_F12	LS-GL	-87.2269	45.6240	GL	LM	F	1						x
171	Robin1_S12	Robin1_S12	LS-GL	-79.8673	42.2198	GL	LE	F	1					x	
159	ROBIN1-GYPSM	ROBIN1-GYPSM	LS-GL	-83.5801	44.1904	GL	LE	F	1						x
160	Robin2_F11	Robin2_F11	LS-GL	-86.5135	43.6209	GL	LM	D	1				x		
172	Robin2_F12	Robin2_F12	LS-GL	-87.2111	45.6237	GL	LM	A	1						x
173	Robin2_S12	Robin2_S12	LS-GL	-79.9197	42.2098	GL	LE	F	1					x	
161	ROBIN2-GYPSM	ROBIN2-GYPSM	LS-GL	-83.5758	44.1822	GL	LE	E	1						x
63	ROCK1	Rockville Array	LS-FC	-94.3626	45.4711	Middle	MC	K	0						x
64	ROCK2	Rockville Array	LS-FC	-94.3626	45.4719	Middle	MC	K	0						x
65	ROCK3	Rockville Array	LS-FC	-94.3638	45.4742	Middle	MC	K	0						x
66	ROCK4	Rockville Array	LS-FC	-94.3637	45.4778	Middle	MC	K	0						x
45	ROSE1	Prairie Rose	BA	-96.3117	43.8430	SW	SW	L	0		x	x	x	x	
46	ROSE2	Prairie Rose	BA	-96.3017	43.8046	SW	SW	L	0		x	x	x	x	
47	ROSE3	Prairie Rose	BA	-96.2911	43.7834	SW	SW	L	0		x	x	x	x	
48	ROSE4	Prairie Rose	BA	-96.3311	43.7691	SW	SW	L	0		x	x	x	x	
164	RPLCE-MAY	MAY	LS-GL	-87.7564	43.7803	GL	LM	C	1					x	
165	RPLC-IN630A	Fowler Ridge WF	DTT	-87.2737	40.5612	Middle	EA	M	1						x
166	RPLC-PV1	Paynesville	BA	-94.7629	45.4131	Middle	MC	K	1					x	x
167	RPLC-TX4	Wolf Ridge WF	WF	-97.4420	33.7241	Middle	TX	O	1						x
134	SEUL-CH0IX	SEUL-CH0IX	LS-GL	-85.9119	45.9211	GL	LM	A	1						x
143	SLEEPER	SLEEPER	LS-GL	-83.2105	43.9777	GL	LM	E	1						x
128	SWU	SWU	LS-GL	-87.7000	43.7663	GL	LM	C	1				x	x	
49	TG1500	Tallgrass Array	LS-GR	-96.3149	43.7328	SW	SW	L	0	x	x	x	x		
50	TG200	Tallgrass Array	LS-GR	-96.2971	43.7328	SW	SW	L	0			x	x		
51	TG2-X-PR1	Tallgrass Array	LS-GR	-96.3117	43.8430	SW	SW	L	0			x	x		
52	TG500	Tallgrass Array	LS-GR	-96.3022	43.7288	SW	SW	L	0	x	x	x	x		
53	TG5K	Tallgrass Array	LS-GR	-96.3522	43.7288	SW	SW	L	0	x	x				

#	Code	Name	Primary Objective	Long	Lat	3Reg	Reg	Obj	BA					
54	TGR	Tallgrass Array	LS-GR	-96.2863	43.7314	SW	SW	L	0	x	x	x	x	
162	TIFFT	TIFFT	LS-GL	-78.8826	42.8855	GL	LE	F	1				x	x
19	TOP1	Top of Iowa WF	WF	-93.4608	43.3936	Middle	MS	I	0		x	x	x	x
20	TOP2	Top of Iowa WF	WF	-93.3895	43.3862	Middle	MS	I	0		x	x	x	x
21	TOP3	Top of Iowa WF	WF	-93.4083	43.3733	Middle	MS	I	0		x	x	x	x
22	TOP4	Top of Iowa WF	WF	-93.3790	43.3563	Middle	MS	I	0		x	x	x	x
67	TX1	Wolf Ridge WF	WF	-97.4159	33.7118	Middle	TX	O	0	x	x	x	x	x
68	TX2	Wolf Ridge WF	WF	-97.3642	33.7295	Middle	TX	O	0	x	x	x	x	x
69	TX3	Wolf Ridge WF	WF	-97.3887	33.7510	Middle	TX	O	0	x	x	x	x	x
70	TX4	Wolf Ridge WF	WF	-97.4420	33.7241	Middle	TX	O	0	x	x	x	x	x
144	USG1	USG1	LS-GL	-83.5670	44.1870	GL	LH	E	1					x
145	USG2	USG2	LS-GL	-83.5587	44.1905	GL	LH	E	1					x
129	WASH	WASH	LS-GL	-87.9668	43.0548	GL	LM	C	1			x	x	
168	WEHLE	WEHLE	LS-GL	-76.2686	43.8723	GL	LO	G	1			x	x	x
135	WELLS	WELLS	LS-GL	-87.3635	45.3968	GL	UP	A	1					x

Reference lists for objectives and regional classifications:

Primary Objective	
WF	Wind farm fatalities (Obj. 3)
LS-FC	Landscape (Obj. 4) – Forested corridor
LS-GR	Landscape (Obj. 4) – Grassland
LS-GL	Landscape (Obj. 4) – Great Lakes
BA	Before-After (Obj. 5)
DTT	Distance to Turbine (Obj. 6)

3Reg	3 Region
GL	Great Lakes Coasts
Middle	Cent. MN, IA, WI, PA, IN, TX
SW	Southwest MN

10Reg	10 Region
EA	East - Indiana and Penna.
LE	Lake Erie
LH	Lake Huron
LM	Lake Michigan
LO	Lake Ontario[1]
MC	Minnesota Central
MS	Minnesota Southern
SW	Southwest Minnesota
TX	Texas
UP	Upper Peninsula Michigan
WE	Wisconsin Eastern

15reg	15 Region
A	Michigan, Upper Peninsula
B	Wisconsin, Door Peninsula
C	Lake Michigan, Western
D	Lake Michigan, Eastern
E	Michigan, Saginaw Bay
F	Lake Erie, Southern
G	Lake Ontario[1]
H	Wisconsin, Eastern (inland)
I	Minnesota, Southeastern
J	Minnesota, South-central
K	Minnesota, Central
L	Minnesota, Southwestern
M	Indiana, Eastern
N	Pennsylvania, Southwestern
O	Texas, Northern
P	Texas, Southern

[1]This region contains only one recording site, and is not included in most analyses

Appendix B

Pass Rates and environmental variables. See below table for Ecoregion classifications. Ecoregion numbers identify the Level 3 Ecoregion, and letters identify the Level 4 Ecoregion, as Level 4 regions are components of larger Level 3 regions.

| | | Bats | | | | Birds | | | | Environment | | | |
| | | All Years | SiteYear | | | All Years | SiteYear | | | Ecoreg | Distance to | | |
ID	Name	SiteMean	2010	2011	2012	SiteMean	2010	2011	2012	L3L4	Water	Trees	Turbine
1	B1	8.18	7.17	9.19	8.00	11.44	17.67	9.93	0.00	47c	2279	691	745
2	B2	4.43	6.95	3.48	2.11	1.37	3.08	0.65	0.00	47c	1011	510	708
3	B3	4.86	6.52	3.68	4.44	4.02	9.99	0.61	0.00	47c	2027	130	593
130	BAILEY	524.86		208.39	616.84	122.90		25.56	151.19	51g	186	2	-
146	Batman1_F11	73.53		73.53		16.80		16.80		57e	336	5	-
147	Batman1_F12	11.50			11.50	11.50			11.50	50aa	2380	103	-
148	Batman1_S12	96.48			96.48	0.75			0.75	83a	137	10	-
149	BATMAN1-KUHL	2.03			2.03	2.03			2.03	57e	764	66	-
150	Batman2_F11	57.54		57.54		15.30		15.30		57e	229	16	-
151	Batman2_F12	5.74			5.74	294.79			294.79	50aa	392	5	-
152	Batman2_Kuhl_F12	63.66			63.66	63.66			63.66	57e	136	20	-
153	Batman2_S12	294.79			294.79	34.51			34.51	83a	121	25	-
106	BELGIUM	6.63		20.56	0.71	96.85		46.54	118.23	53d	915	5	-
136	BETSIE	99.42		68.85	137.07	91.23		165.29	0.00	51m	58	120	-
98	BLUE1	6.71		4.03	8.45	2.26		0.64	3.32	53c	503	109	284
99	BLUE2	46.93		44.28	50.46	10.14		4.79	17.28	53c	172	10	260
100	BLUE3	77.16		76.26	78.09	21.08		6.05	36.82	53c	251	10	1345
101	BLUE4	15.66		12.49	19.15	8.72		7.74	9.81	53c	211	38	425
36	BM1500	4.47	2.34	5.88		5.47	13.39	0.20		47a	704	479	-
37	BM200	1.48		1.48		0.08		0.08		47a	558	291	-
38	BM500	1.24	0.38	2.05		6.43	13.29	0.02		47a	266	585	-

#	Name	C1	C2	C3	C4	C5	C6	C7	C8	Code	C10	C11	C12
39	BM5K	2.68	2.68			0.31	0.31			47a	479	99	-
40	BMR	1.06	1.26	0.12		0.22	0.27	0.00		47a	1095	430	-
107	BRUEM	264.46		151.81	300.40	149.69		183.60	138.88	53d	126	20	-
41	BUFF1	2.94		0.00	8.27	1.09		0.81	1.61	46m	518	413	191
42	BUFF2	1.65		0.58	3.00	3.01		3.01	3.02	46m	546	405	583
43	BUFF3	88.27			88.27	15.99			15.99	46k	112	10	866
44	BUFF4	5.53		1.58	10.49	21.33		30.95	9.25	46m	65	240	661
154	CEDAR	128.34		181.95	90.81	25.02		60.77	0.00	57a	22	25	-
102	CEDAR1	16.36		10.46	21.95	9.80		3.65	15.64	53c	838	5	156
103	CEDAR2	7.52		0.83	10.24	11.47		23.41	6.63	53c	102	90	634
104	CEDAR3	18.90		16.63	21.73	10.87		7.46	15.11	53c	562	10	1127
105	CEDAR4	10.83		9.11	12.59	4.81		2.12	7.58	53c	832	30	277
155	ERIE-E	238.17			238.17	0.00			0.00	83a	676	80	-
156	ERIE-W	173.37			173.37	0.00			0.00	83a	326	5	-
157	EVANGOLA	265.54		402.38	207.18	56.84		190.10	0.00	83a	201	75	-
142	FISH	51.21			51.21	48.50			48.50	57e	57	116	-
108	FOREST	37.88		45.43	33.80	19.63		43.93	6.50	53d	78	93	-
109	FOREST-10KM	194.31			194.31	154.15			154.15	53b	90	15	-
110	FOREST-6KM	32.46			32.46	18.52			18.52	53d	14	5	-
132	GARDEN1	305.80			305.80	180.21			180.21	50aa	270	12	-
133	GARDEN2	166.45			166.45	46.45			46.45	50aa	345	7	-
163	GL-RPLC1 (PB)	321.50			321.50	180.06			180.06	53d	1072	58	-
4	GM101A	42.45			42.45	35.73			35.73	47c	511	590	50
5	GM101B	39.90			39.90	34.42			34.42	47c	613	516	200
6	GM101C	38.04			38.04	34.87			34.87	47c	288	248	500
7	GM107A	33.64			33.64	25.20			25.20	47c	1004	331	50
8	GM107B	43.37			43.37	38.33			38.33	47c	857	401	200

#	Name												
9	GM127A	40.32			40.32	37.68			37.68	47c	557	471	50
10	GM127B	41.09			41.09	35.89			35.89	47c	584	580	200
11	GM127C	31.46			31.46	26.69			26.69	47c	1005	310	500
12	GM161A	12.09			12.09	10.59			10.59	47c	1435	420	50
13	GM161B	18.05			18.05	16.72			16.72	47c	1630	439	200
14	GM161C	43.29			43.29	41.74			41.74	47c	1594	333	500
137	HOLLAND	45.61		39.10	53.95	76.06		135.43	0.00	56d	233	20	-
78	IN095A	18.80			18.80	12.08			12.08	54a	289	290	50
79	IN095B	11.14			11.14	6.19			6.19	54a	317	434	200
80	IN095C	20.96			20.96	8.11			8.11	54a	144	404	500
81	IN396A	16.39			16.39	8.78			8.78	54a	700	330	50
82	IN396B	11.34			11.34	6.11			6.11	54a	828	528	200
83	IN396C	12.09			12.09	7.01			7.01	54a	843	823	500
84	IN480A	18.84			18.84	11.99			11.99	54a	363	311	50
85	IN480B	29.04			29.04	12.40			12.40	54a	233	437	200
86	IN480C	69.59			69.59	26.07			26.07	54a	669	29	500
87	IN630A	30.91			30.91	15.53			15.53	54a	1453	631	50
88	IN630B	14.83			14.83	6.86			6.86	54a	1312	778	200
89	IN630C	14.41			14.41	7.39			7.39	54a	1395	240	500
23	J1500	2.50	3.02	2.16		0.37	0.72	0.14		47b	1853	121	-
24	J200	4.86		4.86		0.02		0.02		47b	221	193	-
25	J500	3.97	5.00	2.32		1.25	2.03	0.00		47b	308	305	-
26	J500-F2011	3.18		3.18		0.00		0.00		47b	308	305	-
27	J5K	4.84	4.84			3.50	3.50			47b	9	54	-
28	J5K-2	3.95	3.95			0.00	0.00			47b	9	54	-
29	J5-X-JR	37.81		37.81		0.00		0.00		47b	180	15	-
30	JR	56.86	62.31	46.94		0.01	0.00	0.03		47b	180	15	-

111	KEWA	101.49		67.99	113.25	153.59		189.28	141.05	47b	17	22	-
112	KEWA-10KM	100.22			100.22	95.05			95.05	53d	239	5	-
113	KEWA-6KM	472.89			472.89	110.93			110.93	53d	736	20	-
114	LSSP	90.30		102.41	62.56	0.00		0.00	0.00	53d	60	245	-
31	M1500	10.05	9.92	10.16		1.36	2.84	0.03		47b	7	486	-
32	M200	24.35		24.35		0.04		0.04		47b	303	207	-
33	M500	14.20	19.08	10.67		0.00	0.00	0.00		47b	625	534	-
34	M5K	6.11	6.11			0.00	0.00			47b	389	2454	-
115	MAY	61.87		66.64	5.29	133.70		144.98	0.00	53d	1298	2	-
138	MEARS	107.40		116.40	95.73	1.07		0.00	2.45	56d	351	20	-
35	MR	85.99	117.94	65.61		50.47	0.00	82.38		47b	125	32	-
131	MUD	608.38		342.20	684.07	188.66		204.65	184.11	51g	758	2	-
139	MUSK	31.30		31.63	30.91	67.71		126.08	0.00	56d	470	62	-
140	NORTH	96.62		101.89	91.08	21.62		38.48	3.88	56d	195	33	-
15	OAK1	77.36		48.29	104.19	29.05		1.68	54.32	47c	605	10	1170
16	OAK2	4.46		6.37	0.00	31.90		43.22	5.44	47c	458	180	270
17	OAK3	130.02		105.34	168.26	35.05		20.47	57.64	47c	470	18	863
18	OAK4	36.54		20.78	54.10	52.27		85.24	15.52	47c	1068	105	590
141	ORCHARD	154.86		94.19	216.32	0.00		0.00	0.00	51m	112	13	-
90	PA1	6.33		6.33						69a	678	67	59
91	PA2	25.22		25.22						69a	158	106	119
92	PA3	21.38		21.66						69a	538	16	72
93	PA4	16.02		16.02						69a	600	20	83
94	PA5	7.53		7.53						69a	296	28	62
95	PA6	6.84		6.84						69a	212	26	87
96	PA7	12.38		12.38						69a	325	146	125
97	PA8	17.70		17.70		101.52		101.52		69a	211	151	81

#	Name												
121	PB	97.36		142.22	6.27			0.00	0.00	53d	452	14	-
118	PB10m_F12	125.68			125.68				84.05	53d	34	21	-
119	PB2_2010	12.62	12.62			0.00	0.00			53d	652	693	-
120	PB3_2010	50.95	50.95			0.00	0.00			53d	420	5	-
123	PB-3m	44.70		9.15	80.26				4.86	53d	390	241	-
124	PB4_2010	0.11		0.11		0.00	0.00			53d	1000	23	-
125	PB6m_F12	77.58		77.58					35.02	53d	121	15	-
71	PSCAL2	31.03		31.03						34i	648	372	547
72	PSCAL3	181.13		181.13						34d	33	2228	409
73	PSCAL4	55.45		55.45						34i	1404	1353	154
74	PSCAL5	58.43		58.43						34i	792	180	637
75	PSCAL6	20.60		20.60						34i	873	2062	464
76	PSCAL7	24.06		24.06						34i	391	1833	238
77	PSCAL8	106.50		106.50						34d	247	162	1216
126	Pt Bch IN_F11	15.94		3.27				0.00		53d	390	241	-
117	Pt Bch_F11	83.50		142.22	24.78					53d	1072	58	-
169	Pt Bch_F12	6.27			6.27					53d	452	14	-
55	PV1	61.95	70.62	43.59	96.78	2.16	0.00	0.01	9.17	51l	37	112	-
56	PV2	15.33	4.05	9.50	29.91	0.95	0.00	0.01	2.71	51l	118	489	-
57	PV3	12.60	5.27	11.30	16.74	2.73	0.00	0.00	5.40	51l	573	90	-
58	PV4	4.52	1.45	2.62	6.87	3.87	0.00	6.45	3.09	51l	419	553	-
59	PV5	106.36			106.36	48.21			48.21	51l	68	2	-
60	PV6	17.12			17.12	19.46			19.46	51l	115	94	-
61	PV7	9.06			9.06	7.66			7.66	51l	242	484	-
62	PV8	12.88			12.88	0.91			0.91	51l	111	95	-
158	Robin1_F11	33.53		33.53		53.07		0.00		56d	1246	56	-
170	Robin1_F12	112.29			112.29				73.47	50aa	675	219	-

#	Name												
171	Robin1_S12	344.52			344.52				81.50	83a	8	10	-
159	ROBIN1-GYPSM	42.71			42.71	42.71			42.71	50ah	25	52	-
160	Robin2_F11	58.70		58.70		96.02		0.00		56d	2060	14	-
172	Robin2_F12	546.79			546.79				444.50	50aa	11	70	-
173	Robin2_S12	420.72			420.72				15.19	83a	35	4	-
161	ROBIN2-GYPSM	155.55			155.55	155.55			155.55	50ah	12	39	-
63	ROCK1	172.78			172.78	155.67			155.67	51k	123	7	-
64	ROCK2	80.76			80.76	74.58			74.58	51k	211	24	-
65	ROCK3	56.93			56.93	48.54			48.54	51k	255	228	-
66	ROCK4	116.22			116.22	103.51			103.51	51k	853	20	-
45	ROSE1	0.99	1.28	0.66		4.40	7.69	0.63		47a	384	141	-
46	ROSE2	0.41	0.38	0.43		3.83	10.64	0.29		47a	6	867	-
47	ROSE3	0.80	1.95	0.45		10.98	46.58	0.06		47a	925	270	-
48	ROSE4	0.62	0.66	0.61		28.57	0.00	39.32		47a	723	587	-
164	RPLCE-MAY	212.89			212.89	0.00			0.00	53d	1298	2	-
165	RPLC-IN630A	17.30			17.30	17.30			17.30	54a	1453	631	50
166	RPLC-PV1	56.88			56.88	36.32			36.32	51l	37	112	-
167	RPLC-TX4	3.26			3.26	3.26			3.26	29d	621	200	202
134	SEUL-CH0IX	1149.01			1149.01	1035.58			1035.58	50aa	135	21	-
143	SLEEPER	421.68			421.68	372.02			372.02	57e	450	10	-
128	SWU	150.44		211.25	30.42	0.00		0.00	0.00	53d	53	55	-
49	TG1500	3.77	2.80	4.52		0.37	0.85	0.00		47a	651	47	-
50	TG200	0.45		0.45		0.00		0.00		47a	404	486	-
51	TG2-X-PR1	0.36		0.36		0.00		0.00		47a	384	141	-
52	TG500	1.15	0.62	1.52		0.03	0.07	0.00		47a	584	670	-
53	TG5K	0.76	0.76			5.01	5.01			47a	1301	493	-
54	TGR	1.13	0.87	1.34		33.54	0.00	59.29		47a	229	352	-

162	TIFFT	27.93		26.87	28.40	1.19		2.03	0.82	83a	266	147	-
19	TOP1	60.76		53.39	70.22	22.09		10.06	37.54	47b	452	142	1560
20	TOP2	67.46		48.51	94.49	18.71		13.94	25.51	47b	861	44	475
21	TOP3	65.51		52.51	81.53	29.05		5.50	58.07	47b	6	216	203
22	TOP4	22.76		8.80	40.43	14.89		0.14	33.56	47b	512	1659	1162
67	TX1	5.51	2.81	9.97	3.14	0.81	0.00	0.00	2.35	29d	619	388	332
68	TX2	4.98	2.91	6.97	4.60	1.14	0.00	0.00	3.50	29d	364	572	209
69	TX3	4.82	3.14		7.67	0.19	0.00		0.52	29d	560	80	137
70	TX4	10.90	1.38	18.50	7.42	4.63	11.06	0.00	5.83	29d	621	200	202
144	USG1	59.81			59.81	57.63			57.63	50ah	76	42	-
145	USG2	92.57			92.57	90.77			90.77	50ah	241	113	-
129	WASH	80.78		82.65	76.08	111.85		139.13	43.12	53b	25	19	-
168	WEHLE	43.98		21.36	46.14	70.35		0.00	77.07	83c	572	2	-
135	WELLS	488.88			488.88	488.88			488.88	50aa	18	26	-

Reference lists for Level 3 and 4 Ecoregion (Ecoreg) classifications:

Level 3 Ecoregion	Ecoregion Name
29	Cross Timbers
34	Western Gulf Coast Plain
46	Northern Glaciated Plains
47	Western Corn Belt Plains
50	Northern Lakes and Forests
51	North Central Hardwood Forests
53	Southeastern Wisconsin Till Plains
54	Central Corn Belt Plains
56	Southern Michigan/Northern Indiana Drift Plains
57	Huron/Erie Lake Plains
69	Central Appalachians
83	Eastern Great Lakes Lowlands

Level 4 Ecoregion	Ecoregion Name
29d	Grand Prairie
34d	Coastal Sand Plain
34i	Laguna Madre Barrier Islands and Coastal Marshes
46k	Prairie Coteau
46m	Big Sioux Basin
47a	Loess Prairies
47b	Des Moines Lobe
47c	Eastern Iowa and Minnesota Drift Plains
50aa	Menominee-Drummond Lakeshore
50ah	Tawas Lake Plain
51g	Door Peninsula
51k	McGrath Till Plain and Drumlins
51l	Wadena/Todd Drumlins and Osakis Till Plain
51m	Manistee-Leelanau Shore
53b	Kettle Moraines
53c	Southeastern Wisconsin Savannah and Till Plain
53d	Lake Michigan Lacustrine Clay Plain
54a	Illinois/Indiana Prairies
56d	Michigan Lake Plain
57a	Maumee Lake Plain
57e	Saginaw Lake Plain
69a	Forested Hills and Mountains
83a	Erie/Ontario Lake Plain
83c	Ontario Lowlands

Appendix C

Estimated total (top, in blue) and average (bottom, in red) pass counts by species, with standard errors in parentheses. RecNights = number of nights during which a recorder was collecting data at the site. Total pass counts were calculated using only passes automatically identified by Kaleidoscope (AutoID), and do not include NoID passes. Average counts include both passes identified by Kaleidoscope and NoId's. Averages were estimated with the assumption that the species composition of NoID passes was identical to that of the AutoID passes at each site. Estimates and standard errors are based on a multinomial distribution of true pass identities for each AutoID species classification, for each region (10Region in Appendix A). Error is only that associated with the species identification process. Since the variance of the distribution of true pass identities among NoID calls cannot be estimated, and the NoID category may contain species other than the eight focal species included in the analysis, standard errors are not listed for these estimates.

	RecNights	EPFU	LABO	LACI	LANO	MYLU	MYSE	NYHU	PESU
TOTAL PASSES									
B1	381	7 (1.11)	61 (4.95)	32 (1.68)	9 (0.96)	510 (5.95)	4 (1.15)	21 (2.91)	18 (2.86)
B2	338	4 (0.46)	29 (2.4)	11 (0.74)	4 (0.44)	168 (2.82)	1 (0.37)	13 (1.68)	9 (1.4)
B3	354	6 (0.54)	27 (2.18)	23 (0.83)	7 (0.59)	176 (2.58)	1 (0.37)	10 (1.46)	8 (1.27)
BAILEY	171	318 (102.0)	2902 (307.3)	279 (81.66)	25 (2.05)	29111 (383.1)	324 (88.8)	1433 (222.6)	1329 (221.5)
BATMAN1	66	155 (13.82)	141 (14.48)	740 (18.62)	214 (15.67)	641 (16.38)	9 (2)	96 (11.76)	101 (11.84)
BATMAN1-KUHL[2]	172	na	na	na	na	na	na	na	na
BATMAN2	62	84 (9.4)	192 (19.78)	121 (7.08)	63 (3.78)	2082 (27.16)	56 (11.73)	126 (14.22)	90 (13.99)
BATMAN2KUHL	285	73 (3.31)	31 (3.31)	81 (3.42)	54 (3.24)	79 (3.95)	4 (0.99)	34 (2.76)	16 (2.44)
BELGIUM	285	25 (1.82)	28 (2.79)	72 (2.17)	32 (1.98)	162 (3.31)	3 (0.62)	28 (2.26)	14 (2.07)
BETSIE	154	227 (14.68)	67 (6.9)	331 (17.91)	292 (17.95)	421 (8.35)	14 (2.94)	64 (5.34)	34 (5.19)
BLUE1	244	14 (2.26)	24 (3.43)	72 (2.42)	13 (1.8)	139 (4.37)	7 (2.21)	3 (1.26)	9 (2.29)

[2] No passes were automatically identified by Kaleidoscope for this site

	RecNights	EPFU	LABO	LACI	LANO	MYLU	MYSE	NYHU	PESU
BLUE2	313	139 (15.73)	160 (22.71)	463 (13.29)	51 (7.6)	879 (29.72)	50 (16.45)	21 (9.16)	62 (14.96)
BLUE3	305	256 (33.92)	481 (63.9)	976 (30.74)	140 (18.44)	1788 (70.79)	85 (27.85)	80 (24.71)	194 (47.12)
BLUE4	282	33 (8.85)	145 (19.65)	264 (8.46)	21 (3.76)	554 (20.8)	16 (5.5)	19 (6.84)	60 (14.76)
BM1500	318	14 (0.88)	19 (2.38)	50 (1.12)	15 (1.07)	6 (1.66)	0 (0)	13 (2.1)	3 (1.22)
BM200	169	1 (0.1)	2 (0.27)	6 (0.12)	1 (0.11)	1 (0.19)	0 (0)	1 (0.23)	0 (0.14)
BM500	269	0 (0.13)	4 (0.47)	12 (0.22)	2 (0.19)	3 (0.34)	0 (0)	2 (0.41)	1 (0.25)
BM5K	128	6 (0.4)	1 (0.14)	20 (0.43)	6 (0.41)	1 (0.21)	0 (0)	1 (0.12)	1 (0.16)
BMR	154	2 (0.15)	1 (0.13)	7 (0.2)	3 (0.2)	0 (0.09)	0 (0)	1 (0.12)	0 (0.07)
BRUEM	277	544 (86.09)	1846 (184.9)	695 (56.73)	257 (15.66)	18509 (255.4)	549 (115.6)	1805 (138.3)	879 (131.21)
BUFF1	306	21 (1.28)	7 (0.86)	68 (1.46)	18 (1.38)	2 (0.6)	0 (0)	3 (0.76)	1 (0.44)
BUFF2	288	3 (0.27)	7 (0.86)	16 (0.28)	3 (0.25)	4 (0.64)	0 (0)	5 (0.76)	1 (0.47)
BUFF3	273	125 (10.48)	31 (3.9)	816 (16.23)	205 (15.21)	10 (2.72)	0 (0)	18 (3.44)	5 (2)
BUFF4	131	16 (1.8)	6 (0.7)	187 (2.91)	20 (2.47)	6 (0.58)	0 (0)	5 (0.6)	2 (0.44)
CEDAR	136	141 (10.67)	248 (26.96)	403 (11.28)	140 (9.18)	598 (30.85)	4 (0.81)	192 (22.26)	149 (20.22)
CEDAR1	302	55 (6.36)	49 (6.59)	282 (7.51)	42 (5.55)	194 (7.25)	8 (2.64)	7 (2.42)	20 (4.87)
CEDAR2	201	8 (2.16)	17 (2.44)	106 (2.52)	6 (1.37)	92 (2.77)	2 (0.78)	1 (0.68)	8 (1.75)
CEDAR3	332	46 (7.21)	109 (14.81)	144 (7.88)	48 (6.29)	385 (15.67)	14 (4.7)	12 (5.31)	47 (11.2)
CEDAR4	296	23 (3.41)	39 (5.38)	119 (4.19)	26 (3.5)	99 (5.42)	4 (1.27)	5 (2)	17 (4.17)
ERIE-E	65	166 (16.33)	318 (58.67)	214 (18.19)	83 (9.56)	2828 (74.63)	56 (16.53)	130 (35.61)	399 (51.5)

	RecNights	EPFU	LABO	LACI	LANO	MYLU	MYSE	NYHU	PESU
ERIE-W	70	308 (27.56)	90 (17.73)	356 (28.28)	261 (28.96)	417 (22.71)	13 (3.65)	70 (11.88)	74 (15.21)
EVANGOLA	97	84 (22.49)	471 (84.2)	192 (21.81)	68 (8.06)	4765 (109.7)	121 (34.27)	238 (50.83)	905 (76.91)
FISH	70	115 (5.46)	13 (1.54)	246 (6.46)	84 (5.6)	24 (1.71)	0 (0)	10 (1.23)	8 (1.58)
FOREST	114	13 (1.19)	27 (2.79)	14 (0.87)	5 (0.35)	274 (3.68)	6 (1.37)	13 (2.04)	12 (1.99)
FOREST-10KM	208	213 (20.25)	474 (48.96)	761 (21.09)	155 (13.86)	4054 (60.13)	61 (14)	263 (37.16)	240 (35.72)
FOREST-6KM	84	13 (1.06)	26 (2.81)	41 (1.08)	7 (0.75)	102 (3.28)	2 (0.33)	18 (2.31)	12 (2.07)
GARDEN1	190	199 (55.93)	1626 (167.8)	172 (38.38)	32 (2.16)	12971 (206.7)	249 (53.37)	1138 (130.1)	750 (121.54)
GARDEN2	214	100 (30.28)	383 (44.35)	47 (18.45)	6 (0.39)	6143 (75.78)	222 (46.88)	169 (27.34)	165 (29.14)
GM101A	60	8 (1.31)	81 (6.55)	39 (2.07)	10 (1.12)	615 (7.81)	4 (1.31)	32 (4.11)	24 (3.81)
GM101B	73	6 (1.17)	75 (6.13)	21 (1.9)	7 (0.99)	606 (7.32)	4 (1.26)	27 (3.69)	24 (3.57)
GM101C	70	854 (1.71)	1565 (6.42)	1697 (2.32)	598 (1.31)	16394 (7.88)	429 (1.93)	813 (3.36)	1440 (3.66)
GM107A	44	1 (0.36)	24 (1.99)	5 (0.59)	2 (0.31)	165 (2.35)	1 (0.34)	9 (1.32)	8 (1.16)
GM107B	76	8 (1.49)	79 (6.44)	53 (2.3)	14 (1.4)	675 (7.74)	4 (1.49)	29 (3.72)	26 (3.73)
GM107C	70	8 (1.71)	78 (6.42)	30 (2.32)	13 (1.31)	741 (7.88)	6 (1.93)	24 (3.36)	25 (3.66)
GM127A	82	5 (1.27)	63 (5.17)	19 (1.69)	4 (0.77)	574 (6.31)	5 (1.5)	20 (2.84)	19 (2.94)
GM127B	85	14 (2.07)	121 (9.74)	52 (3.08)	14 (1.65)	900 (11.64)	7 (2.11)	56 (6.22)	37 (5.65)
GM127C	80	13 (1.82)	54 (4.77)	29 (2.14)	16 (1.34)	625 (6.12)	7 (2.04)	14 (1.84)	17 (2.59)
GM161A	64	4 (0.54)	17 (1.45)	16 (0.81)	8 (0.69)	99 (1.72)	1 (0.29)	8 (1.02)	5 (0.84)
GM161B	61	2 (0.38)	23 (1.87)	10 (0.65)	5 (0.44)	143 (2.2)	1 (0.25)	8 (1.27)	7 (1.1)

	RecNights	EPFU	LABO	LACI	LANO	MYLU	MYSE	NYHU	PESU
GM161C	68	6 (1.12)	78 (6.68)	30 (1.98)	11 (1.19)	406 (7.8)	2 (0.67)	33 (4.78)	23 (3.93)
HOLLAND	146	50 (2.78)	37 (4.12)	66 (3.1)	50 (3)	73 (4.71)	0 (0.07)	28 (3.39)	22 (3.08)
IN095A	80	8 (1.63)	52 (4.79)	49 (1.91)	15 (1.84)	28 (3.98)	0 (0)	24 (3.65)	19 (3.3)
IN095B	80	6 (0.5)	31 (2.76)	4 (0.43)	4 (0.45)	21 (2.3)	0 (0)	13 (2.08)	10 (1.88)
IN095C	80	1 (0.39)	39 (3.48)	4 (0.08)	0 (0.38)	31 (2.98)	1 (0.51)	15 (2.61)	11 (2.33)
IN396A	74	3 (1.29)	59 (5.33)	63 (1.3)	2 (0.28)	37 (4.44)	0 (0.17)	25 (4.04)	21 (3.64)
IN396B	74	4 (0.83)	33 (3.02)	28 (0.95)	7 (0.87)	19 (2.52)	0 (0.17)	13 (2.29)	9 (2.06)
IN396C	76	4 (0.81)	27 (2.44)	33 (0.89)	6 (0.71)	15 (2.03)	0 (0.06)	11 (1.85)	8 (1.67)
IN480A	76	6 (1.86)	38 (3.42)	90 (1.9)	7 (0.77)	23 (2.85)	0 (0)	21 (2.6)	14 (2.35)
IN480B	80	5 (0.65)	58 (5.36)	15 (0.76)	7 (0.77)	30 (4.46)	0 (0.11)	26 (4.07)	17 (3.66)
IN480C	70	4 (0.92)	217 (19.61)	35 (0.78)	4 (0.66)	141 (16.33)	1 (0.39)	108 (14.84)	63 (13.37)
IN630A	45	12 (1.41)	56 (5.1)	52 (1.5)	12 (1.27)	31 (4.24)	0 (0.06)	36 (3.9)	18 (3.51)
IN630B	76	5 (0.93)	28 (2.53)	19 (1.11)	10 (1.13)	15 (2.1)	0 (0.06)	15 (1.94)	10 (1.75)
IN630C	80	1 (0.57)	42 (3.86)	28 (0.59)	2 (0.22)	23 (3.2)	0 (0)	22 (2.93)	14 (2.64)
J1500	319	4 (0.51)	3 (0.29)	39 (0.77)	7 (0.64)	12 (0.34)	0 (0.01)	2 (0.29)	1 (0.17)
J200	183	6 (0.8)	8 (0.73)	67 (1.18)	6 (0.82)	32 (0.85)	0 (0.08)	6 (0.67)	3 (0.43)
J500	317	14 (1.3)	6 (0.56)	100 (1.91)	19 (1.56)	23 (0.66)	0 (0.04)	7 (0.66)	2 (0.34)
J5K	176	5 (0.73)	5 (0.43)	61 (1.07)	7 (0.79)	14 (0.5)	0 (0.01)	3 (0.46)	1 (0.25)
JR	265	82 (4.15)	18 (1.46)	110 (4.77)	58 (4.37)	94 (1.91)	1 (0.23)	15 (1.1)	7 (0.89)
KEWA	277	205 (24.12)	553 (57.43)	1009 (26.36)	201 (18.68)	3684 (68.97)	65 (14.04)	406 (45.68)	264 (42.13)
KEWA-10KM	211	187 (15.75)	204 (22.29)	853 (20.98)	116 (15.67)	542 (25.77)	8 (1.64)	199 (18.51)	102 (17.08)

	RecNights	EPFU	LABO	LACI	LANO	MYLU	MYSE	NYHU	PESU
KEWA-6KM	205	1640 (68.3)	549 (57.26)	1590 (61.1)	619 (52.39)	2006 (67.18)	55 (11.95)	659 (48.04)	276 (42.55)
LSSP	158	80 (7.88)	78 (8.1)	440 (10.8)	112 (8.86)	144 (9.19)	0 (0.05)	132 (7.12)	45 (6.49)
M1500	296	17 (2.84)	34 (2.72)	231 (4.15)	15 (2.82)	273 (3.28)	2 (0.69)	13 (2.15)	10 (1.56)
M200	193	41 (3.98)	68 (5.62)	313 (5.87)	50 (4.49)	415 (6.61)	2 (0.81)	37 (4.21)	20 (3.3)
M500	322	41 (4.11)	48 (3.96)	313 (6.09)	58 (4.93)	284 (4.66)	1 (0.5)	27 (3.16)	15 (2.33)
M5K	132	3 (0.32)	5 (0.43)	12 (0.49)	6 (0.46)	26 (0.5)	0 (0.04)	2 (0.3)	1 (0.25)
MAY	90	66 (4.04)	65 (6.61)	201 (4.93)	50 (3.92)	214 (7.59)	3 (0.68)	97 (5.71)	35 (5.03)
MEARS	147	425 (23.83)	114 (12.57)	681 (28.56)	471 (28.22)	371 (14.23)	9 (1.91)	87 (10.04)	58 (9.54)
MR	285	346 (22.44)	289 (23.64)	1442 (30.95)	338 (25.97)	2632 (28.85)	20 (6.37)	109 (14.38)	84 (13.56)
MUD	271	477 (136.9)	2026 (232.5)	315 (92.93)	31 (2.25)	32780 (367.9)	959 (201.8)	1054 (136.9)	904 (157.14)
MUSK	162	32 (2.59)	36 (4.01)	89 (3.09)	47 (2.94)	75 (4.61)	0 (0.1)	32 (3.31)	19 (2.97)
NORTH	156	201 (16.34)	90 (9.91)	485 (20.53)	328 (20.44)	180 (11.11)	1 (0.29)	92 (8.04)	49 (7.55)
OAK1	225	51 (10.62)	287 (24.83)	193 (10.12)	25 (3.84)	2992 (32.72)	39 (12.71)	84 (11.26)	80 (12.73)
OAK2	207	3 (0.5)	22 (1.79)	21 (0.69)	4 (0.43)	186 (2.17)	2 (0.49)	11 (1.07)	7 (1.03)
OAK3	260	79 (11.29)	395 (32.71)	525 (14.13)	66 (7.8)	3872 (40.81)	38 (11.74)	144 (16.7)	117 (18.23)
OAK4	277	48 (4.69)	216 (17.43)	222 (6.45)	34 (3.68)	1659 (20.97)	14 (4.3)	87 (10.96)	65 (10.03)
ORCHARD	153	583 (29.75)	253 (26.78)	694 (33.74)	555 (33.12)	753 (30.75)	15 (3.12)	290 (22.25)	127 (19.89)
PA1	54	0 (0.1)	5 (0.45)	1 (0.06)	1 (0.11)	10 (0.45)	0 (0.06)	1 (0.24)	1 (0.27)

	RecNights	EPFU	LABO	LACI	LANO	MYLU	MYSE	NYHU	PESU
PA2	58	6 (1.65)	76 (6.68)	12 (0.97)	11 (1.77)	141 (6.59)	2 (1.47)	26 (4.12)	29 (4.13)
PA3	63	4 (0.61)	24 (2.04)	13 (0.67)	6 (0.72)	39 (1.92)	1 (0.39)	11 (1.34)	18 (1.49)
PA4	61	5 (0.82)	26 (2.3)	11 (0.98)	9 (1.04)	22 (1.94)	0 (0.11)	12 (1.73)	10 (1.58)
PA5	34	2 (0.14)	8 (0.7)	2 (0.11)	1 (0.13)	9 (0.6)	0 (0.06)	4 (0.51)	4 (0.48)
PA6	50	3 (0.57)	11 (0.97)	4 (0.62)	6 (0.7)	17 (0.97)	1 (0.34)	4 (0.67)	5 (0.61)
PA7	42	2 (0.53)	19 (1.82)	5 (0.54)	4 (0.65)	43 (1.88)	1 (0.45)	6 (0.98)	18 (1.35)
PA8	66	5 (0.84)	41 (3.48)	8 (1.01)	8 (1.08)	62 (3.18)	1 (0.45)	19 (2.34)	31 (2.57)
PB	136	138 (7.59)	106 (10.81)	216 (8.17)	128 (7.62)	762 (13.43)	20 (4.11)	87 (8.54)	50 (7.86)
PB-10KM	207	113 (9.02)	155 (16.08)	396 (10.14)	57 (7.21)	1143 (20.28)	32 (6.75)	106 (12.69)	73 (11.8)
PB-6	96	18 (2.72)	58 (6.11)	106 (2.8)	14 (1.92)	331 (7.53)	11 (2.26)	46 (4.96)	27 (4.47)
PBIN	342	71 (7.25)	103 (10.7)	274 (7.21)	37 (4.93)	921 (15.58)	38 (8.26)	71 (8.26)	48 (7.62)
PSCAL2	61	8 (1.55)	85 (7.8)	9 (0.66)	1 (0.51)	81 (6.94)	1 (0.76)	431 (8.56)	18 (4.12)
PSCAL3	70	22 (5.97)	493 (50.42)	130 (2.87)	3 (2.31)	375 (45.7)	0 (0.38)	4315 (65.06)	121 (28.52)
PSCAL4	65	11 (4.76)	231 (22.18)	13 (3.07)	3 (2.51)	183 (19.14)	1 (0.47)	595 (22.23)	45 (11.34)
PSCAL5	56	3 (1.49)	88 (10.5)	20 (1.31)	1 (1.07)	69 (9.69)	0 (0)	1015 (14.5)	24 (6.14)
PSCAL6	70	6 (2.46)	71 (6.7)	14 (2.19)	2 (1.79)	66 (5.83)	0 (0.28)	213 (6.74)	14 (3.43)
PSCAL7	65	1 (0.71)	49 (4.84)	15 (0.44)	0 (0.36)	38 (4.35)	0 (0)	385 (6.04)	12 (2.7)
PSCAL8	64	15 (4.93)	332 (30.68)	16 (1.01)	1 (0.76)	269 (26.73)	1 (0.85)	1393 (32.43)	68 (15.98)
PV1	230	134 (28.75)	17 (4.15)	2088 (39.72)	136 (26.96)	76 (12.01)	1 (1.29)	3 (1.66)	7 (2.87)
PV2	278	43 (5.54)	23 (5.61)	192 (6.76)	65 (6.05)	84 (6.58)	1 (0.94)	7 (2.3)	9 (3.89)

	RecNights	EPFU	LABO	LACI	LANO	MYLU	MYSE	NYHU	PESU
PV3	249	42 (7.52)	37 (10.34)	244 (6.77)	39 (4.07)	93 (11.36)	2 (1.52)	7 (4.51)	15 (7.49)
PV4	260	7 (1.26)	6 (1.6)	27 (1.42)	13 (1.22)	17 (1.75)	0 (0)	3 (0.71)	3 (1.15)
ROBIN1	173	154 (34.03)	352 (65.92)	1000 (31.33)	105 (18.48)	5642 (97.25)	133 (39.18)	124 (37)	295 (61.1)
ROBIN1-GYPSM	55	17 (2.88)	36 (6.62)	79 (2.92)	16 (2.04)	458 (9.18)	12 (3.36)	11 (3.87)	26 (5.91)
ROBIN2	168	305 (42.96)	862 (161.71)	491 (51.58)	289 (32.76)	7451 (205.53)	150 (43.84)	440 (99.47)	689 (140.61)
ROBIN2-GYPSM	62	56 (19.76)	245 (45.98)	45 (9.88)	13 (1.47)	3976 (70.07)	121 (33.86)	75 (23.17)	188 (41.91)
ROCK1	69	79 (22.32)	142 (35.03)	205 (16.2)	33 (6.04)	361 (38.17)	6 (5.5)	61 (15.4)	92 (25.48)
ROCK2	62	111 (15.58)	69 (15.82)	460 (10.93)	57 (6.89)	174 (18.87)	8 (7.48)	44 (6.86)	74 (12.4)
ROCK3	46	61 (6.26)	21 (4.98)	292 (7.3)	66 (6.11)	54 (5.76)	2 (1.52)	9 (2.1)	20 (3.79)
ROCK4	63	89 (6.26)	96 (4.98)	284 (7.3)	99 (6.11)	208 (5.76)	2 (1.52)	22 (2.1)	68 (3.79)
ROSE1	133	1 (0.15)	1 (0.15)	14 (0.25)	3 (0.23)	2 (0.15)	0 (0)	1 (0.13)	0 (0.12)
ROSE2	202	0 (0.04)	2 (0.26)	3 (0.07)	1 (0.07)	1 (0.18)	0 (0)	1 (0.23)	0 (0.14)
ROSE3	243	2 (0.38)	1 (0.13)	12 (0.65)	9 (0.65)	0 (0.09)	0 (0)	1 (0.12)	0 (0.07)
ROSE4	256	1 (0.16)	1 (0.07)	5 (0.27)	4 (0.27)	0 (0.05)	0 (0)	2 (0.08)	0 (0.06)
RPLCE-MAY	47	280 (12.22)	25 (2.48)	351 (11.69)	87 (9.77)	85 (2.86)	2 (0.4)	40 (2.17)	14 (2.47)
SEUL-CHOIX	93	408 (110.0)	1739 (215.4)	297 (88.11)	98 (6.18)	32187 (322.4)	688 (148.9)	694 (109.14)	781 (147.84)
SLEEPER	63	1199 (99.8)	285 (57.69)	1149 (101.5)	909 (100.7)	945 (88.91)	1 (0.18)	844 (76.83)	279 (61.02)
SWU	113	108 (9.86)	228 (23.82)	377 (10.8)	140 (9.19)	577 (27.32)	3 (0.72)	302 (20.22)	123 (17.75)

	RecNights	EPFU	LABO	LACI	LANO	MYLU	MYSE	NYHU	PESU
TEXAS1	305	0 (0.11)	9 (1.06)	3 (0)	0 (0)	8 (0.75)	0 (0)	15 (0.91)	30 (1.12)
TEXAS2	310	0 (0.2)	14 (1.29)	1 (0)	0 (0)	11 (1.1)	0 (0)	46 (1.3)	14 (0.77)
TEXAS3	129	1 (0.51)	18 (1.66)	1 (0.44)	0 (0.36)	12 (1.42)	0 (0)	46 (1.66)	9 (0.87)
TEXAS4	251	0 (0.22)	13 (1.36)	0 (0)	0 (0)	10 (1.17)	0 (0)	12 (1.34)	6 (0.7)
TG1500	300	17 (1.28)	19 (2.32)	80 (1.8)	25 (1.73)	8 (1.66)	0 (0)	10 (2.04)	3 (1.22)
TG200	58	0 (0.01)	0 (0)	1 (0.02)	0 (0.01)	0 (0)	0 (0)	0 (0)	0 (0)
TG500	318	3 (0.3)	8 (0.93)	12 (0.4)	6 (0.4)	4 (0.68)	0 (0)	4 (0.82)	1 (0.5)
TG5K	97	0 (0.04)	1 (0.07)	2 (0.07)	1 (0.07)	0 (0.05)	0 (0)	0 (0.06)	0 (0.03)
TGR	297	2 (0.15)	6 (0.79)	9 (0.2)	3 (0.19)	2 (0.56)	0 (0)	3 (0.7)	1 (0.41)
TIFFT	98	23 (4.53)	56 (10.35)	166 (5.22)	15 (2.94)	710 (14.13)	15 (4.46)	20 (6.38)	51 (9.31)
TOP1	281	60 (8.14)	455 (36.88)	333 (12.48)	70 (7.23)	3439 (44)	24 (7.64)	172 (23.3)	132 (21.4)
TOP2	296	51 (7.4)	318 (26.12)	305 (11.66)	110 (9.23)	2033 (30.8)	13 (4.16)	135 (17.77)	95 (15.25)
TOP3	288	81 (5.69)	218 (17.68)	115 (6.59)	45 (3.95)	1659 (21.53)	17 (5.25)	78 (11.09)	61 (10)
TOP4	290	21 (3.33)	184 (15.02)	189 (5.3)	26 (3.11)	1221 (17.75)	8 (2.49)	94 (10.16)	56 (8.79)
USG1	90	191 (13.93)	82 (15.05)	277 (13.51)	87 (10.86)	925 (20.66)	29 (8.01)	45 (9.4)	61 (13.17)
USG2	88	221 (17.57)	99 (18.78)	368 (18.39)	150 (16.82)	810 (24.09)	21 (5.96)	52 (12.25)	72 (16.2)
WASH	88	208 (19)	16 (3.23)	687 (22.91)	158 (19.05)	48 (5.12)	0 (0.06)	19 (9.69)	12 (2.76)
WEHLE	252	157 (18.23)	115 (22.64)	277 (20.32)	180 (20.43)	420 (29.87)	5 (1.43)	199 (20.39)	96 (20.79)
WELLS	88	154 (46.06)	685 (128.07)	316 (31.27)	47 (6.37)	8954 (174.6)	138 (49.23)	222 (71.52)	527 (116.21)

	RecNights	EPFU	LABO	LACI	LANO	MYLU	MYSE	NYHU	PESU
AVERAGE PASS COUNTS									
B1	381	0.08	0.71	0.37	0.11	5.95	0.04	0.25	0.21
B2	338	0.07	0.52	0.20	0.08	3.01	0.02	0.24	0.16
B3	354	0.09	0.41	0.36	0.11	2.74	0.02	0.16	0.13
BAILEY	171	6.52	59.43	5.71	0.51	596.13	6.64	29.35	27.21
BATMAN1	66	14.28	13.00	68.27	19.75	59.08	0.85	8.84	9.28
BATMAN1-KUHL	172	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BATMAN2	62	5.13	11.67	7.37	3.83	126.78	3.39	7.65	5.50
BATMAN2KUHL	285	2.73	1.14	3.02	2.01	2.94	0.16	1.27	0.58
BELGIUM	285	0.45	0.51	1.31	0.58	2.96	0.05	0.51	0.26
BETSIE	154	17.25	5.10	25.10	22.17	31.94	1.05	4.83	2.60
BLUE1	244	0.32	0.55	1.66	0.31	3.18	0.15	0.06	0.21
BLUE2	313	3.24	3.74	10.82	1.18	20.52	1.16	0.50	1.44
BLUE3	305	4.88	9.18	18.61	2.68	34.11	1.61	1.53	3.71
BLUE4	282	0.46	2.00	3.64	0.29	7.62	0.22	0.26	0.83
BM1500	318	0.51	0.72	1.86	0.56	0.22	0.00	0.49	0.11
BM200	169	0.15	0.23	0.65	0.15	0.14	0.00	0.11	0.04
BM500	269	0.02	0.17	0.55	0.09	0.11	0.00	0.08	0.03
BM5K	128	0.42	0.08	1.37	0.39	0.06	0.00	0.04	0.08
BMR	154	0.10	0.05	0.29	0.13	0.01	0.00	0.02	0.01
BRUEM	277	5.15	17.50	6.58	2.43	175.44	5.21	17.11	8.33
BUFF1	306	0.31	0.10	1.03	0.27	0.03	0.00	0.05	0.01
BUFF2	288	0.13	0.28	0.64	0.12	0.16	0.00	0.21	0.06
BUFF3	273	4.18	1.05	27.25	6.87	0.33	0.00	0.61	0.18
BUFF4	131	0.76	0.28	9.03	0.98	0.29	0.00	0.22	0.08

	RecNights	EPFU	LABO	LACI	LANO	MYLU	MYSE	NYHU	PESU
CEDAR	136	9.66	16.99	27.59	9.59	40.91	0.26	13.13	10.22
CEDAR1	302	1.39	1.23	7.10	1.05	4.89	0.20	0.17	0.50
CEDAR2	201	0.25	0.53	3.24	0.18	2.81	0.05	0.03	0.25
CEDAR3	332	1.07	2.56	3.38	1.13	9.04	0.33	0.29	1.10
CEDAR4	296	0.74	1.28	3.87	0.86	3.22	0.13	0.17	0.57
ERIE-E	65	10.29	19.77	13.27	5.15	175.61	3.48	8.07	24.79
ERIE-W	70	27.59	8.09	31.92	23.41	37.33	1.13	6.29	6.60
EVANGOLA	97	3.28	18.31	7.47	2.66	185.15	4.71	9.24	35.16
FISH	70	11.80	1.38	25.36	8.68	2.49	0.00	1.02	0.77
FOREST	114	1.20	2.47	1.32	0.50	25.48	0.60	1.22	1.11
FOREST-10KM	208	6.35	14.10	22.66	4.62	120.68	1.82	7.82	7.15
FOREST-6KM	84	1.92	3.78	6.04	1.07	14.95	0.23	2.70	1.78
GARDEN1	190	3.55	29.00	3.06	0.58	231.35	4.44	20.30	13.38
GARDEN2	214	2.00	7.67	0.95	0.13	122.79	4.43	3.38	3.30
GM101A	60	0.43	4.22	2.01	0.51	32.14	0.21	1.67	1.28
GM101B	73	0.29	3.91	1.08	0.38	31.40	0.19	1.40	1.26
GM101C	70	35.10	64.30	69.73	24.57	673.51	17.61	33.41	59.15
GM107A	44	0.13	2.06	0.45	0.19	13.98	0.09	0.79	0.66
GM107B	76	0.32	3.05	2.05	0.55	26.01	0.17	1.11	0.98
GM107C	70	0.34	3.21	1.25	0.53	30.43	0.25	0.99	1.04
GM127A	82	0.20	2.36	0.71	0.16	21.42	0.18	0.74	0.70
GM127B	85	0.47	4.13	1.79	0.49	30.80	0.23	1.91	1.26
GM127C	80	0.53	2.19	1.19	0.63	25.40	0.27	0.58	0.68
GM161A	64	0.22	1.08	1.02	0.52	6.20	0.06	0.50	0.31
GM161B	61	0.15	1.68	0.78	0.36	10.65	0.04	0.61	0.54
GM161C	68	0.33	4.10	1.56	0.58	21.28	0.10	1.74	1.18

	RecNights	EPFU	LABO	LACI	LANO	MYLU	MYSE	NYHU	PESU
HOLLAND	146	6.73	5.07	8.97	6.80	9.87	0.04	3.80	2.99
IN095A	80	0.76	5.03	4.73	1.49	2.71	0.00	2.28	1.79
IN095B	80	0.79	3.88	0.51	0.47	2.66	0.00	1.59	1.23
IN095C	80	0.11	8.07	0.81	0.10	6.46	0.16	3.03	2.22
IN396A	74	0.23	4.60	4.95	0.18	2.87	0.02	1.92	1.62
IN396B	74	0.42	3.25	2.78	0.74	1.92	0.02	1.28	0.93
IN396C	76	0.51	3.06	3.82	0.72	1.76	0.01	1.32	0.90
IN480A	76	0.55	3.59	8.57	0.64	2.17	0.00	1.96	1.37
IN480B	80	0.90	10.64	2.77	1.27	5.46	0.03	4.86	3.10
IN480C	70	0.45	26.31	4.27	0.54	17.13	0.07	13.12	7.67
IN630A	45	1.67	7.98	7.45	1.67	4.44	0.01	5.13	2.57
IN630B	76	0.72	4.03	2.78	1.40	2.18	0.01	2.25	1.45
IN630C	80	0.15	4.60	3.04	0.20	2.47	0.00	2.42	1.53
J1500	319	0.12	0.10	1.19	0.23	0.38	0.00	0.05	0.03
J200	183	0.21	0.31	2.54	0.23	1.23	0.01	0.24	0.10
J500	317	0.26	0.12	1.90	0.35	0.45	0.00	0.13	0.04
J5K	176	0.16	0.14	1.90	0.23	0.43	0.00	0.08	0.04
JR	265	8.17	1.76	10.98	5.81	9.40	0.07	1.51	0.74
KEWA	277	3.05	8.26	15.05	2.99	54.96	0.97	6.06	3.94
KEWA-10KM	211	8.48	9.23	38.65	5.27	24.56	0.35	9.03	4.64
KEWA-6KM	205	93.80	31.42	90.93	35.39	114.73	3.17	37.68	15.79
LSSP	158	6.99	6.85	38.54	9.82	12.60	0.02	11.58	3.91
M1500	296	0.25	0.49	3.38	0.22	3.99	0.03	0.20	0.14
M200	193	1.06	1.74	8.02	1.29	10.63	0.06	0.95	0.52
M500	322	0.69	0.80	5.22	0.97	4.73	0.02	0.46	0.25
M5K	132	0.17	0.32	0.77	0.37	1.68	0.01	0.13	0.09

	RecNights	EPFU	LABO	LACI	LANO	MYLU	MYSE	NYHU	PESU
MAY	90	5.55	5.50	16.99	4.27	18.09	0.27	8.25	2.95
MEARS	147	20.60	5.54	33.01	22.85	17.96	0.43	4.20	2.82
MR	285	5.30	4.43	22.13	5.18	40.39	0.31	1.67	1.29
MUD	271	7.33	31.12	4.84	0.48	503.51	14.73	16.18	13.88
MUSK	162	2.83	3.18	7.81	4.13	6.59	0.04	2.77	1.69
NORTH	156	12.07	5.42	29.07	19.65	10.78	0.08	5.54	2.92
OAK1	225	1.06	5.93	3.98	0.51	61.69	0.81	1.74	1.65
OAK2	207	0.05	0.39	0.37	0.08	3.24	0.03	0.19	0.13
OAK3	260	1.85	9.30	12.35	1.55	91.10	0.89	3.38	2.75
OAK4	277	0.75	3.39	3.48	0.53	26.00	0.22	1.36	1.03
ORCHARD	153	27.70	12.02	32.97	26.36	35.75	0.69	13.79	6.05
PA1	54	0.11	1.52	0.42	0.18	3.28	0.03	0.40	0.41
PA2	58	0.52	6.36	0.97	0.88	11.76	0.18	2.14	2.43
PA3	63	0.73	4.42	2.43	1.05	7.16	0.11	2.02	3.41
PA4	61	0.76	4.44	1.80	1.50	3.79	0.03	2.00	1.70
PA5	34	0.42	2.13	0.45	0.24	2.32	0.02	0.93	1.02
PA6	50	0.35	1.48	0.56	0.77	2.29	0.07	0.60	0.72
PA7	42	0.19	1.95	0.48	0.38	4.43	0.07	0.63	1.88
PA8	66	2.98	24.70	5.01	4.98	37.01	0.40	11.42	18.72
PB	136	6.54	5.03	10.28	6.09	36.19	0.93	4.14	2.39
PB-10KM	207	6.58	9.02	23.09	3.31	66.61	1.87	6.19	4.25
PB-6	96	1.91	6.17	11.26	1.52	35.17	1.13	4.88	2.91
PBIN	342	1.33	1.92	5.11	0.69	17.20	0.72	1.32	0.89
PSCAL2	61	0.37	4.18	0.42	0.04	3.96	0.04	21.14	0.88
PSCAL3	70	0.72	16.37	4.30	0.11	12.43	0.01	143.18	4.01
PSCAL4	65	0.54	11.84	0.65	0.15	9.38	0.03	30.53	2.33

	RecNights	EPFU	LABO	LACI	LANO	MYLU	MYSE	NYHU	PESU
PSCAL5	56	0.15	4.22	0.98	0.06	3.31	0.00	48.55	1.17
PSCAL6	70	0.33	3.80	0.75	0.11	3.50	0.02	11.36	0.73
PSCAL7	65	0.07	2.38	0.71	0.02	1.83	0.00	18.52	0.56
PSCAL8	64	0.78	16.85	0.82	0.06	13.68	0.05	70.79	3.48
PV1	230	3.37	0.42	52.62	3.42	1.92	0.03	0.08	0.17
PV2	278	1.40	0.73	6.22	2.10	2.71	0.03	0.23	0.30
PV3	249	1.12	0.98	6.45	1.02	2.46	0.04	0.20	0.40
PV4	260	0.39	0.38	1.64	0.77	1.03	0.00	0.17	0.15
ROBIN1	173	2.91	6.66	18.91	1.99	106.66	2.52	2.34	5.58
ROBIN1-GYPSM	55	1.13	2.32	5.11	1.04	29.75	0.77	0.69	1.72
ROBIN2	168	6.25	17.62	10.05	5.91	152.38	3.08	9.01	14.10
ROBIN2-GYPSM	62	1.84	8.08	1.49	0.42	131.07	3.98	2.46	6.21
ROCK1	69	14.00	25.14	36.11	5.88	63.71	1.04	10.69	16.22
ROCK2	62	8.99	5.61	37.29	4.58	14.10	0.65	3.55	5.99
ROCK3	46	6.60	2.27	31.77	7.15	5.85	0.18	0.98	2.14
ROCK4	63	11.88	12.89	38.08	13.30	27.82	0.30	2.90	9.05
ROSE1	133	0.06	0.06	0.68	0.14	0.09	0.00	0.07	0.02
ROSE2	202	0.01	0.12	0.16	0.06	0.03	0.00	0.06	0.02
ROSE3	243	0.08	0.03	0.37	0.29	0.01	0.00	0.02	0.00
ROSE4	256	0.04	0.03	0.24	0.19	0.01	0.00	0.10	0.01
RPLCE-MAY	47	67.33	5.93	84.58	20.94	20.50	0.46	9.67	3.48
SEUL-CHOIX	93	12.73	54.25	9.26	3.06	1004.33	21.48	21.66	24.36
SLEEPER	63	90.11	21.46	86.35	68.35	71.02	0.05	63.46	20.95
SWU	113	8.81	18.53	30.65	11.39	46.92	0.24	24.56	9.99
TEXAS1	305	0.00	0.19	0.06	0.00	0.17	0.00	0.32	0.63
TEXAS2	310	0.00	0.24	0.02	0.00	0.19	0.00	0.77	0.24

	RecNights	**EPFU**	**LABO**	**LACI**	**LANO**	**MYLU**	**MYSE**	**NYHU**	**PESU**
TEXAS3	129	0.05	0.85	0.04	0.02	0.59	0.00	2.21	0.45
TEXAS4	251	0.01	0.43	0.00	0.00	0.33	0.00	0.40	0.19
TG1500	300	0.40	0.43	1.84	0.57	0.19	0.00	0.23	0.07
TG200	58	0.01	0.00	0.43	0.01	0.00	0.00	0.00	0.00
TG500	318	0.10	0.23	0.38	0.18	0.13	0.00	0.12	0.04
TG5K	97	0.03	0.09	0.30	0.15	0.02	0.00	0.04	0.01
TGR	297	0.08	0.21	0.31	0.09	0.08	0.00	0.11	0.03
TIFFT	98	0.62	1.48	4.40	0.40	18.76	0.39	0.53	1.35
TOP1	281	0.70	5.36	3.92	0.83	40.55	0.28	2.03	1.55
TOP2	296	1.07	6.66	6.40	2.32	42.65	0.27	2.83	2.00
TOP3	288	2.18	5.87	3.09	1.20	44.74	0.45	2.10	1.64
TOP4	290	0.23	2.07	2.13	0.29	13.76	0.09	1.06	0.63
USG1	90	6.74	2.88	9.76	3.06	32.63	1.01	1.57	2.16
USG2	88	11.39	5.12	18.97	7.75	41.81	1.10	2.71	3.71
WASH	88	13.69	1.04	45.15	10.39	3.14	0.01	1.26	0.78
WEHLE	252	4.73	3.46	8.36	5.43	12.66	0.15	6.00	2.88
WELLS	88	6.84	30.47	14.05	2.08	398.15	6.13	9.89	23.45