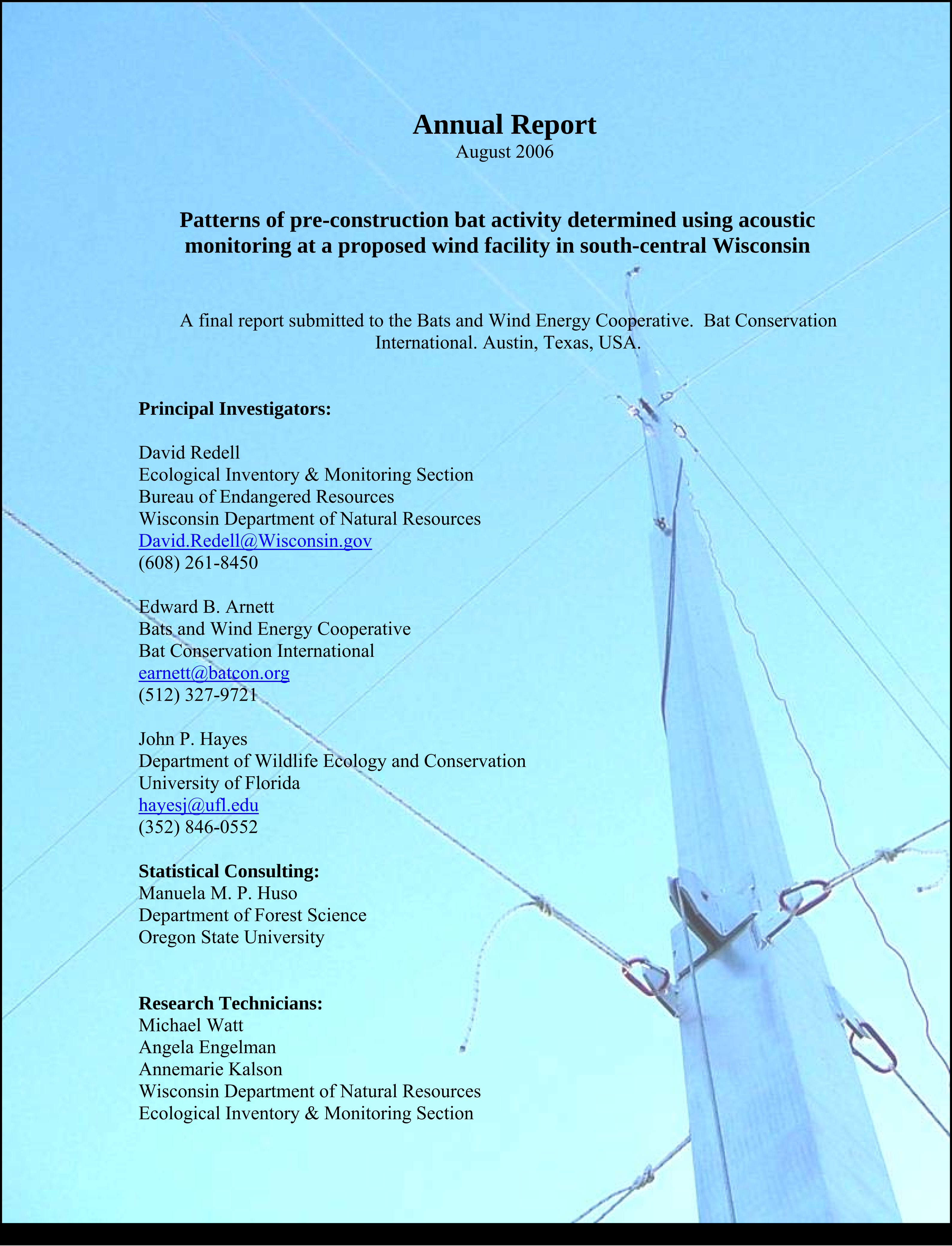

Annual Report
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Patterns of pre-construction bat activity determined using acoustic monitoring at a proposed wind facility in south-central Wisconsin

A final report submitted to the Bats and Wind Energy Cooperative. Bat Conservation International. Austin, Texas, USA.

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Executive Summary

We initiated a 3-year study in mid-summer 2005 to determine patterns of bat activity and evaluate the use of acoustic monitoring to predict fatality of bats at a proposed wind energy facility in south-central Wisconsin. The study area represents a situation where a large bat hibernaculum is within proximity to the proposed turbine locations. The primary objectives of this study are to 1) combine these data with other similar studies to evaluate whether indices of pre-construction bat activity can be used to predict relative risk of post-construction bat fatalities at proposed wind facilities; 2) determine the levels and patterns of activity of different species groups of bats using the area of the proposed wind facility; 3) determine temporal and spatial patterns of bat activity at turbine locations across the wind facility and vertically using detectors positioned at ground level (2m), within the turbine rotor-swept zone (48 m above the ground), and at an intermediate level (22 m above the ground); 4) determine if patterns of post-construction bat fatality are related to and may be predicted by pre-construction activity, weather conditions, and other environmental conditions. The goal of the study is to provide information to minimize mortality of bats migrating to Neda Mine and through the area (foliage roosting bats heading south). In addition, results of our study will help evaluate the efficacy of acoustic monitoring to assess risk of bat fatality at proposed wind power sites.

We used broadband ultrasound detectors during the 2005 fall migration period (19 July through September) to assess the spatial and temporal distribution of bat activity across the proposed wind farm location, two reference areas, and two sites located near the Neda Mine. We used 50 m meteorological towers and 22 m tall, portable, telescoping towers to vertically array detectors for acoustic sampling during this study. We recorded bat echolocation calls at proposed turbine locations using detectors arranged on 3 meteorological towers (one detector at 2, 22, and 48 m high at each tower) and rotated 5 mobile towers (one detector at 2 and 22m high at each tower) throughout the study period to sample the 33 proposed turbine locations.

We recorded a total of 26,495 bat passes at all towers throughout the study. Feeding-type activity was identified in 3998 passes (15 % of total bat passes); and feeding activity appeared to occur throughout the night and at all heights sampled. Bat activity was highly variable throughout the study and varied considerably among the towers. Recorded bat activity was highest in August with secondary peaks in late July and September. By October bat activity had declined considerably.

Two species groups were defined using the average minimum call frequency of each bat pass recorded. High frequency group included species with the average minimum call frequency ≥35 kHz (Little brown bat, *Myotis lucifugus;* Northern long-eared bat, *Myotis septentrionalis;* Eastern pipistrelle, *Pipistrellus subflavus;* and Eastern Red bat, *Lasiurus borealis*) and low frequency group as <35 kHz (Big brown bat, *Eptesicus fuscus;* Silver-haired bat, *Lasionycteris noctivagans;* and Hoary bat, *Lasiurus cinereus*).

The two species groups tended to fly at different heights at the Wisconsin site. Activity of high frequency bats was estimated to be 3.2–5.5 times higher at 2 m than at 22 m, and 3.8–7 times higher at 2 m than at 48 m. There was no detectable difference in activity at any height for the low frequency bats, nor at the higher altitudes (22 vs. 48 m) for the high frequency bats. We estimated that activity of high frequency bats was 2–7.3 times higher than that of low frequency bats at 2 m. At higher altitudes (22 and 48 m), the activity of low frequency bats was not detectably different than that of high frequency bats.

Myotis species (primary inhabitants of the Neda Mine) were treated as a subgroup within the high frequency species group to assess bat activity in relation to a turbine's distance from the mine and habitat features. We found that relative activity of *Myotis* bats at 2 m decreased by between 6 and 28% for every kilometer increase in distance of a tower from the Neda Mine. There was no detectable relationship of relative activity with distance from the mine for low frequency bats.

Temperature and wind speed affected bat activity rates at our site, but the effect of temperature differed for the two species groups. Temperature during this study ranged from 7–26 ºC. The effect of temperature was very strong, and differed for the two groups. For each 1ºC increase in temperature, the activity rate of the high frequency group was estimated to increase by 3-9% and the activity rate of the low frequency group was estimated to increase by 7-13%. Average nightly wind speed during this study ranged from 1.0–9.6 m/s and strongly affected bat activity. For each increase in wind speed of 1 m/s, the activity rate of bats was estimated to decrease by 4-13%. Bat activity decreased with increasing wind speed, but there was still some activity, even at the highest wind speeds measured in this study.

INTRODUCTION

Wind has been used to commercially produce energy in North America since the early 1970s and is one of the most rapidly growing sectors of the energy industry. Wind turbines generate electricity without many of the negative environmental impacts associated with other energy sources (e.g., air and water pollution, greenhouse gas emissions associated with global warming and climate change). However, fatalities of bats have been recorded at wind facilities worldwide, including in Australia (Hall and Richards 1972), North America (Erickson et al. 2002, Johnson et al. 2003, 2004, Fiedler 2004, Kerns and Kerlinger 2004, Arnett 2005), and northern Europe (Ahlen 2002, 2003). Bat fatality at wind facilities received little attention until 2003 when 1,400–4,000 bats were estimated to have been killed at the Mountaineer Wind Energy Center in West Virginia (Kerns and Kerlinger 2004). Documentation of continued high bat fatality at Mountaineer in 2004 (Arnett 2005) coupled with survey data from Tennessee indicating equal and higher kill rates than Mountaineer (Fiedler 2004; Tennessee Valley Authority, unpublished data) support the contention that forested ridges in the eastern U.S. are high risk sites for bat fatality. No data exist on the level of bat fatality related to wind facilities sited in proximity to major bat hibernacula.

Interactions between bats and wind turbines are poorly understood. The combination of nocturnal habits, volancy, small size, and variation in resource dependence (i.e., species vary in roost, water, and food resource dependence), have made even a rudimentary understanding of how bats interface with their environment difficult to establish (Gannon et al. 2003). Post-construction monitoring has provided most of what little information has been gathered on bat activity patterns at wind farms. While patterns of fatality of bats at wind facilities allow for some conjecture about risk factors for some species, information on use of the area encompassing a facility are needed to place bat fatality in an appropriate context (Fiedler 2004). Pre-construction surveys at wind facilities have been conducted and most commonly employ mist nets and acoustic detectors to assess local bat species' presence and activity. However, using this information to predict bat fatality and, thus risk at a site has proved to be challenging. The ability to generate reliable risk assessments prior to construction of wind facilities is greatly hampered by the lack of baseline data on bat population distributions and densities throughout North America (O'Shea et al. 2003, Reynolds 2006) and migratory patterns and behavior of bats (Larkin 2006).

Acoustic monitoring allows researchers to detect and record calls of echolocating bats that can be used to assess relative activity and identify species or groups of species. Monitoring echolocation calls has limitations and acoustic detectors often are used in the field without a thorough understanding of these limitations, the underlying assumptions, or the use of standardized protocols (Hayes 2000, Sherwin et al. 2000, Weller and Zabel 2002, Gannon et al. 2003). Estimating amount of activity is relatively straightforward, but estimating abundance requires differentiation between multiple passes of a single bat and multiple bats making single passes, and is not usually possible. Echolocation calls are reliably distinguishable from other sounds (e.g., bird, arthropod, wind, mechanical), but ability to distinguish species of bats varies with taxon, location, type of equipment, and quality of recording, and may be challenging (Barclay 1999, Hayes 2000).

Understanding bat activity levels prior to construction of wind facilities could assist in identifying habitats and features that pose high risk of fatality and aid with decision-making, including specific placement of turbines (Fiedler 2004, Reynolds 2006). Unfortunately, some past efforts to acoustically monitor bat activity prior to construction of turbines may suffer from study design flaws, including small sample sizes and poor temporal and spatial replication (Hayes 1997, 2000), pseudoreplication (Hurlbert 1984), and inappropriate inference because limitations and assumptions were not understood or clearly articulated (Hayes 2000, Sherwin et al. 2000, Gannon et al. 2003). Also, there is a lack of information and lack of agreement among stakeholders, biologists, and scientists regarding what different mortality levels at wind facilities mean in terms of population consequences. Perhaps most importantly, we currently are unaware of any study that has correlated pre-construction monitoring data with post-construction fatality, a fundamental link necessary for understanding potential risk of wind facilities to bats.

We initiated a study in summer 2005 to evaluate whether indices of bat activity gathered before construction using acoustic detectors can predict post-construction fatality of bats at a proposed wind facility in south-central Wisconsin. This project will occur in 2 phases. The first phase collected echolocation calls to develop indices of bat activity from 19 July through September, 2005. The second phase will begin post-construction and involve extensive fatality searches for a minimum of two years. Here, we present the results from the 2005 field season, discuss patterns of bat activity, and outline next steps for this project.

OBJECTIVES

1. Combine results from this study with similar studies to evaluate if indices of pre-construction bat activity can be used to predict relative risk of post-construction bat fatalities at a site.
2. Determine the levels and patterns of activity of different species groups of bats using the area of the proposed wind facility in Dodge County, Wisconsin.
3. Determine temporal and spatial patterns of bat activity at turbine locations across the wind facility and vertically using detectors positioned at ground level (2m), within the turbine rotor-swept zone (48 m above the ground), and at an intermediate level (22 m above the ground).
4. Determine if patterns of post-construction bat fatality are related to and may be predicted by pre-construction activity, weather conditions, and other environmental conditions.

Study Area and Significance

The study area is located in Dodge County in south-central Wisconsin. Mean annual temperature is 6.9°C with an annual precipitation of 82.6 cm and winds prevailing out of the southwest. Glacial till plains and moraines characterize the landscape with elevation varying from 275–350 m above sea level. Land use in this area is typical of the region of southern Wisconsin with a mix of agriculture, woodlands, and locally concentrated development (Anderson et al. 2002). Within the study area, the landscape is dominated by agricultural crop fields, many of which are bordered by tree lines and an occasional forest patch or woodlot. All proposed turbine locations are sited within open type habitat i.e., agricultural fields, but vary in distance to tree line or forest edge features.

The Niagara Escarpment, a ridge of dolomite that extends from Dodge County 275 km to the tip of Door County, is a prominent landscape feature in Wisconsin with respect to geology, elevation, and current vegetation cover (Anderson et al. 2002). The abandoned iron ore mine in Neda, Wisconsin, is situated at the southern end of the Niagara Escarpment and is one of the largest known bat hibernacula in the midwestern United States (Redell 2005). After the

Neda Mine was identified as a significant hibernaculum, state and federal agencies, academic and non-profit groups, and private organizations cooperated to improve conditions at the mine for bats and fund preliminary research on bat activity at the mine. A past estimate reported there could be as many as 300,000 little brown bats (*Myotis lucifugus*), and hundreds of northern long-eared bats (*M. septentrionalis*), eastern pipistrelles (*Pipistrellus subflavus*), and big brown bats (*Eptesicus fuscus*) using the mine as a hibernaculum (J. S. Altenbach, Department of Biology, University of New Mexico, unpublished data 1995) ranking the Neda Mine State Natural Area among the largest remaining hibernacula in North America (Tuttle 1996). The most recent census placed the hibernating population between 140,000 and 146,000 bats (Redell 2005). The bats that hibernate in the mine may originate from an area covering thousands of square kilometers (Tuttle 1996), thus possibly representing a significant portion of the total midwestern United States' bat population.

The areas surrounding the escarpment may be an important habitat and migration corridor for wildlife and much of this part of WI is currently sited for wind farm development as it is considered a Wind Resource Area (WRA) (Anderson et al. 2002). In addition to the four bat species found at the Neda Mine, Wisconsin has three species of bat known to occur in the study area that do not use the site for hibernation. No data exist to describe the migration timing and spatial patterns of these three species of foliage roosting bats (eastern red bat [*Lasiurus borealis*], hoary bat [*Lasiurus cinereus*], silver-haired bat [*Lasionycteris noctivagans*] passing through the study area as they head south for the winter. The majority of activity by these bats is expected to occur during spring and autumn migration; however, there may be some level of resident bat activity during the summer.

In recent years studies have indicated that bats risk fatal collision with wind turbines and there is a growing body of evidence indicating that fatalities of bats are often much greater than birds in many areas (e.g., Fiedler 2004, Johnson et al. 2004, and Arnett 2005). While voluntary, the United States Fish and Wildlife Service released *Interim guidelines to avoid and minimize wildlife impacts from wind turbines* (USFWS, 2003). Within these guidelines under Site Development Recommendations within WRA's, one of the ten recommendations is to "avoid placing turbines near known bat hibernation, breeding, and maternity/nursery colonies, in migration corridors, or in flight paths between colonies and feeding areas" (USFWS, 2003). Though the USFWS does not define "near" in terms of distance, the Butler Ridge Wind Farm project involves the installation of approximately thirty-three wind turbines with the closest turbines planned for 3.2 km (2 miles) and the furthest turbine sites located 6.9 km (4.3 miles) from the Neda Mine hibernaculum (Figure 1).

Turbines installed at the Butler Ridge Wind Farm will likely be one of the following designs: **1)** Suzlon 2.1 MW wind turbine (model S88) with a tower height of 80 m (263 ft) and rotor diameter of 88 m (289 ft); or **2)** Gamesa 2.0 MW wind turbine (model G87) with a tower height of 80 m (263 ft) and rotor diameter of 87 m (285 ft). Thus, total height of turbines will be approximately 124 m (408 ft) with the blade sweep zone being 36 – 124 m (118 – 408 ft) above ground.

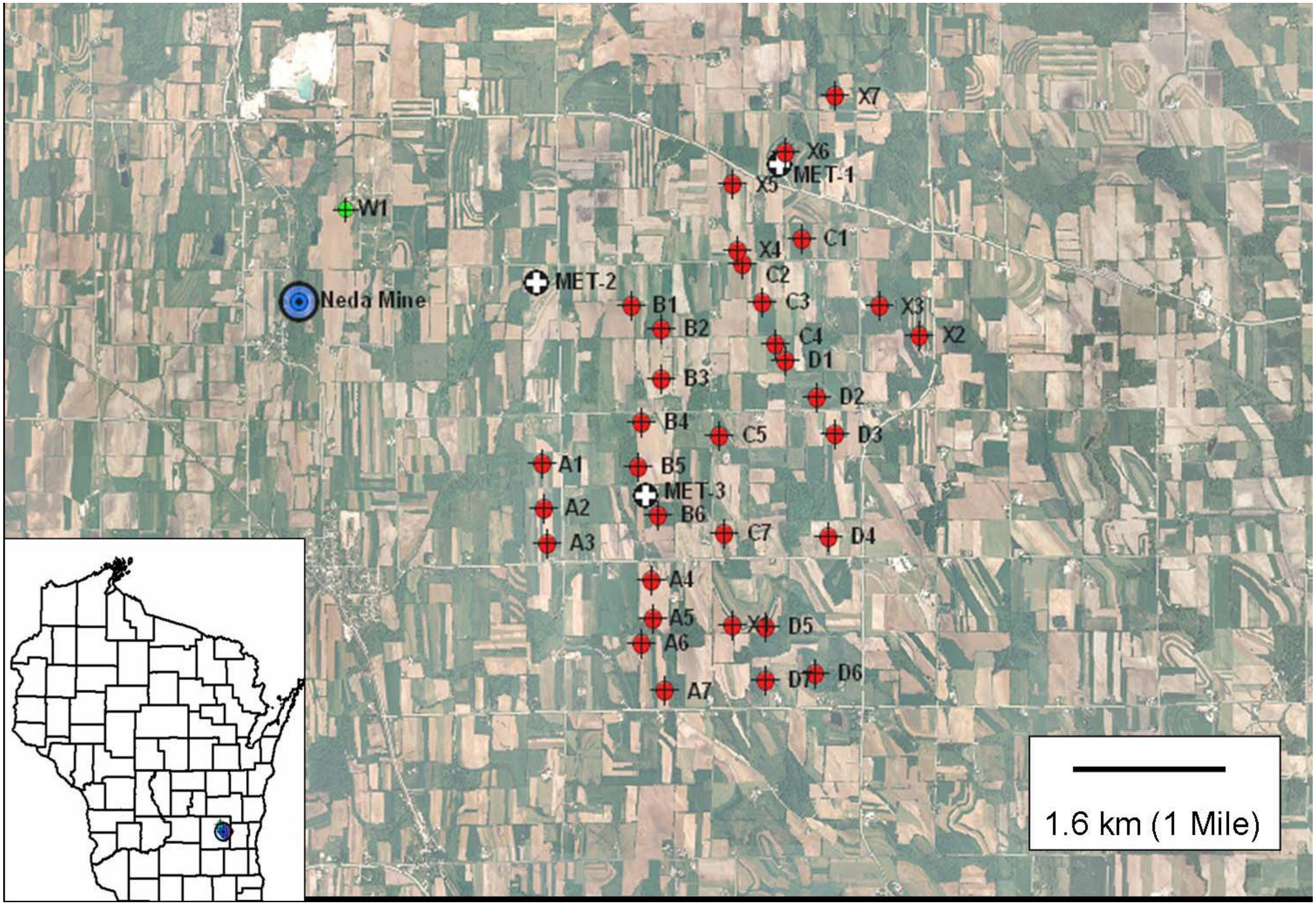


Figure 1. Study area in Dodge County, WI with planned locations of 33 turbines (A1-X7), three 50m meteorological towers (MET 1, 2, & 3), and the Neda Mine State Natural Area bat hibernaculum. Site W1 was also monitored for bat activity.

METHODS

Acoustic Surveys

Monitoring bat activity. We recorded bat echolocation calls using broadband acoustic detectors (Anabat II zero-crossing ultrasonic detectors and CF-ZCAIM storage unit, Titley Electronics Pty Ltd, Ballina, NSW Australia) during the pre-construction phase. Each detector was programmed to record data from 30 min prior to sunset to 30 min after sunrise each night of the study. We calibrated sensitivity of Anabat detectors according to Larson and Hayes (2000) at the beginning of the field season. To further control for detector variance we rotated detector positions between sampling heights during weekly moves to new site locations.

We established 37 stations for acoustic sampling of bat echolocation calls: 33 stations at planned turbine locations, at each of 3 meteorological (hereafter MET) towers constructed to evaluate conditions at the proposed wind power facility and 1 station near two relatively small wind turbines (Vestas 65/12.6 kW) approximately 1.1 km northeast of the Neda Mine. Two reference locations outside the study area were selected for additional monitoring throughout the study period. Both reference locations were placed within open grassland habitat and were subjectively chosen to ensure site access; one site was located 7.6 km northwest of Neda Mine on state land (43.47442°N, 88.59982°W) and the second site was located 12 km north northwest of the Neda Mine on federal land (43.52463°N, 88.59460°W). Reference locations are used to assess annual changes in activity not associated with wind farm attraction / avoidance. At the 33 planned turbine locations and the additional site 1.1 km from Neda Mine (these 34 sites are hereafter referred to as "mobile towers") we recorded bat echolocation calls using detectors positioned 2 and 22 m above the ground on portable, telescoping towers (Force 12, Inc., Paso Robles, CA). We chose this size of mobile tower based on trade-offs between maximum height (Figure 2), portability, and cost. We subjectively chose to place towers 40 m away (approximately one rotor blade length) from the proposed turbine location, while maintaining distance to nearest tree line or forest edge, in an attempt to establish the same sampling sites which can be used during post-construction monitoring without interfering with turbines during operation.

We also positioned detectors on each of three existing MET towers within the study area. The height of meteorological towers allowed acoustic monitoring at a height that reached into the lower half of the rotor-swept zone of turbines likely to be installed at this facility. Three acoustic detectors were vertically arranged at each of the 3 MET towers at 2, 22, and 48 m above the ground. The height of 48 m corresponds to the highest location detectors could be placed on the 50 m tower without interfering with the installed weather sensors. The 22 m height corresponds to the highest point on portable towers used during this study. The 9 detectors at the 3 MET towers stayed in place for the duration of the field season to record bat activity every night. We deployed microphones for each detector within water-resistant casings (a.k.a. "bat-hats;" Figure 3; EME Systems, Berkeley, California, USA) attached to Canare Star Quad™ microphone cable that extended to the ground, where detectors were placed in waterproof military surplus storage boxes (Figure 4). Sound reflector plates on the microphone enclosures were positioned 15 degrees below horizontal so that the main acceptance angle was directed upward at 45 degrees (Figure 3) (Weller and Zabel 2002). Pre-amp drivers were installed with each microphone enclosure to prevent signal loss due to cable length. We used insulative solar shields to cover the military storage boxes to reduce daytime heating effects from the sun on the electronics.

We sampled 5 of the 34 mobile tower sites per 5-night sample period. Using random selection of sites without replacement, we rotated among stations until all mobile tower locations had been sampled. Thus, it took 7 sample periods to cover all sites. Once the full rotation was complete, we began a new round of random selection sampling and continued until the end of the field season. Two rotations were sampled for each of these 34 sites which provided 10 sample nights per location. Due to equipment failure some sites were sampled fewer than 10 sample nights. Echolocation calls and weather data were collected for 75 consecutive nights, from 19 July through September, 2005. MET and reference tower data were collected through 28 October; however, this data for the month of October was not used in the analysis as there were no weather or mobile tower data during that period.

A bat pass was defined as a series of ≥ 2 consecutive echolocation calls having <1 second separating each call (Hayes 1997; Thomas 1988; Seidman and Zabel 2001). During identifications to species sound groups and to *Myotis* sp., we also recorded whether the bat pass contained a feeding buzz (Griffin et al. 1960). Feeding attempts were visually identified in this study using Analook software with no time compression, and were defined as a rapid increase in pulse repetition rate followed by a slight pause with no calls before returning to the pass's initial call rate. While feeding buzzes are not identifiable in passes containing few calls, we used total passes to index proportion of feeding attempts. We considered each feeding buzz to be an attempted capture of an insect (Grindal and Brigham 1999) and as a way to index foraging activity. While a direct comparison among studies is subjective due to variation among researchers in classifying feeding buzzes (Hayes 2000), this information was used for a seasonal comparison with spring data collected at the Neda Mine site (Redell 2005) and for assessing patterns in feeding by detector height and time of night.

Separating recordings into species sound groups. Once data were collected, trained technicians cleaned non-bat pass recordings (i.e., insect, wind, rain, EMI, files with 1 bat call, etc) from the dataset using AnalookW. The remaining filtered files were then analyzed and each bat pass was assigned to one of two sound groups while further separating *Myotis* sp. passes within the high frequency group (based on reference call recordings from Illinois and Wisconsin). The species found in Wisconsin form two sound groups, four with high frequency calls defined as having passes with an average minimum call frequency ≥ 35 kHz (*Myotis lucifugus*, *M. septentrionalis*, *Pipistrellus subflavus*, and *Lasiurus borealis*) and three with low frequency calls identified as having a pass with an average minimum call frequency < 35 kHz (*L. cinereus*, *Lasionycteris noctivagans*, and *Eptesicus fuscus*) (Redell 2005).

Assumptions Following Hayes (2000), Sherwin et al. (2000), and Gannon et al. (2003), we defined a priori that: 1) a bat pass was considered a sequence of echolocation calls consisting of two or more individual calls (Thomas 1988, O'Farrell and Gannon 1999, Gannon et al. 2003); 2) passes were treated as independent (i.e., any sequence was considered a discrete event); and 3) replication was defined as multiple systems running simultaneously at multiple sites within the sampling period. We assumed that 1) species consistently call at either high or low frequencies and 35 kHz (average minimum call frequency) can be used as a threshold to accurately separate these species into two groups; 2) temporal and spatial variation would be adequately accounted for through simultaneous sampling at 8 sites per night; 3) amount of bat passes recorded reflects amount of use by bats; and 4) identification of the proportion of passes containing feeding buzzes reflects the relative amount of foraging activity and the ability to identify foraging activity remains constant across sites and heights.

Analyses These data will be used in conjunction with information collected in phase 2 of the study to evaluate relationships between pre-construction activity data and post-construction patterns of use, as well as relationships between recorded levels of activity and post-construction fatalities.

Data summary methods. In the study area, three permanent meteorological towers (referred to as MET towers) were established at three locations on the site (at the planned locations of turbines on Neno Road, Rock Road and Arthur Road, labeled MET 1, MET 2, and MET 3, respectively) to continuously record wind speed and temperature. MET tower weather data were available from 19 July through 1 October, 2005. MET data were collected every 10 minutes and averaged across towers and over 10-minute samples to give nightly average wind speed and temperature. Wind speed was measured at 10 m, 30 m and 50 m at all towers. Air temperature was measured at 3m at all towers. Mobile towers were placed at each planned turbine location twice throughout the season, for a total of 10 nights. There was one exception (X2) where bat passes were recorded for one five night stretch, and occasional malfunctions of equipment that resulted in missing data interspersed throughout the data set.

Wind speed at heights at which bats were measured (2 m, 22 m and 48 m) were interpolated from measured wind speeds at 10, 30, and 50 m. Wind speed increased linearly with height, so interpolation was justified. High and low frequency bat passes at each of the three heights on each night were summed to give a total number of passes in each of these 6 categories on each of the 75 nights of this study. Not all AnaBat detectors functioned correctly on every night and not all towers recorded bats at all heights. The response was standardized as the number of bat passes per tower, by dividing by the total number of passes recorded for each species group at each height on each night by the number of functioning detectors at each height. Our final data set had 450 observations (2 species groups * 3 heights * 75 nights). Each night had a unique value of average nightly temperature, and wind speed on each night was interpolated for each height.

Statistical Methods

Weather variables & detector height. This study was designed to estimate activity rates (number of passes/tower) of bats and differences in those rates based on two factors, species sound group (those with high frequency calls and those with low frequency calls) and height above the ground (2 m, 22 m, 48 m). We hypothesized (using a two-sided alternative) that bats of one species group might have a tendency to migrate, commute, or forage at different altitudes than the other species group. Other studies have reported that activity rates can change depending on temperature and wind speed (e.g., Reynolds 2006), but how these latter two factors would affect the activity patterns of the two groups at this study site was unknown. To explore these relationships, we developed a large set of plausible models describing the interaction of temperature and/or wind speed with each other and with each of the design factors (species group and height). Julian date and the quadratic effect of date were included in all models to account for the seasonal nature of bat activity that peaked in August. The design factors (species group and height) and their interactions were also included in all models. The compared models included temperature and/or wind speed and/or combinations of their possible interactions with the design factors. In addition to linear effects of temperature and wind speed, we included potential quadratic effects that would indicate an optimal temperature or wind speed for bat activity. Although the data are counts, i.e. number of passes per night in each factor combination, and would naturally be modeled as Poisson distributed, the observed values were generally quite high and there was much more variation than expected of Poisson distributed data. The data appeared to be adequately modeled as lognormal with an offset equal to the $\log_e$ (the number of functioning towers available to measure the activity). We used Akaike's Information Criterion (AIC) to compare the models and to identify the best model or models in the set. This technique is described in detail in Burnham and Anderson (2002). The full set of compared models is provided in Appendix I.

Spatial variability, proximity to Neda Mine and habitat features. This study was designed to determine spatial variability in relative activity rates among tower locations, whether activity rates were higher at tower locations closer to the Neda Mine (Figure 1), as well as to assess activity rates related to the proximity of tree line and forest edge features (e.g. Figure 22) and water sources (excluding intermittent streams and ephemeral ponds). Two measurements related to edge were included as variables for model selection; 1) the distance to nearest tree line or forest edge in 4 cardinal directions (most edge features are oriented N-S and E-W in the study area) was averaged for each turbine location as a contextual measure of edge and 2) a single measure of distance to the nearest tree line or forest edge. Distance from each tower to the nearest perennial water source was identified using Wisconsin DNR 24k Hydrography GIS layer and aerial photographs. The environmental variables of interest were unique to each tower, and hypotheses regarding the effect of these variables on relative change were on the tower level. Each tower was considered an experimental unit in this analysis repeatedly measured for high and low frequency groups. Relative change in activity rates at the two heights were modeled separately. Repeated measures analysis was used to model the potential correlation among the two species groups at the same tower.

Because bat activity measurements at proposed towers did not all occur over the same time period, activity rates at the proposed towers were not directly comparable without accounting for different weather conditions during their monitoring periods. We thus used the MET towers as a reference, assuming that activity rates at these towers would rise and fall relative to changes in weather variables at the site. Deviation in activity rate at each tower on each night at each of two heights was calculated as the ratio in the activity rate at the tower (total number of passes of each species) / (average number of passes at the three Met towers of each species). This value was log-transformed to stabilize variance and was used in the statistical analysis. Relative activity was averaged over the measured dates for each site (usually 10 nights). The final data set used in this analysis had 136 observations (34 sites * 2 species groups * 2 heights), with some missing values.

We developed a set of plausible linear models (Appendix III) describing the relationship of relative activity to various environmental factors measured on each tower. All models included the species group design factor (hilow). Models differed by inclusion of each environmental variable: distance to the mine (distmine), distance to the nearest water source (distwater), average minimum distance in four cardinal directions to forest edge or tree line (avedge), and the distance to the nearest edge (near edge) and its interaction with species group. Only one-variable models were proposed for *Myotis*. Average relative activity appeared to follow a lognormal distribution and assumptions of homogeneity of variance and symmetry of residuals were adequately met for all models. Akaike's Information Criterion (AIC) was used to compare the models and to identify the best model or models in the set.

Figure 2. 22 m mobile tower used for mounting bat detector microphones at ground level (2 m) and 22 m above ground.

Figure 3. Detector microphone enclosure "Bat Hat" shown mounted at 2m on mobile tower.

Figure 4. Surplus military enclosures used to house multiple detector systems at base of each meteorological and mobile tower.

RESULTS

We recorded a total of 26,495 bat passes at all towers throughout the study. Bat activity was highly variable throughout the study and varied considerably among the towers. Recorded bat activity was highest in August with secondary peaks in July and September. By October bat activity declined considerably. Monthly patterns of activity for each MET tower were consistent; however, the total number of bat passes at each site varied among towers indicating considerable spatial variation within the study area (Figure 5). Average activity from the 3 MET towers indicate temporal variability as well as differences in use of vertical airspace for both high and low frequency species groups (Figures 6, 7, and 8).

Bat activity was highest for the first few hours after sunset with a gradual decline in activity throughout the night followed by a smaller peak in activity before sunrise (Figure 9). A secondary rise in activity before sunrise was not apparent during the month of September as was observed during July and August (Figure 9). Feeding buzzes were identified in 15 % of all bat passes during this study. There were no remarkable patterns observed in the proportion of feeding attempts observed during this study period that could be used to distinguish hour of night or height above ground in which feeding was concentrated. Bat passes containing feeding attempts were identified throughout all hours of the night (Figure 10). Similarly, no obvious feeding patterns emerged among the vertical detector heights (Figure 11). For comparison, the acoustic study during spring migration (April and May) in previous years found the proportion of bat passes containing feeding attempts was less than 1% in both open and edge type habitat (Redell 2005). A comparison of bat activity at the Neda Mine entrances with bat activity recorded within the study area (Figure 12) indicated a similar pattern of activity during the end of July and during the month of August but deviated during September as the index of activity declines at the mine but continues throughout the study area.

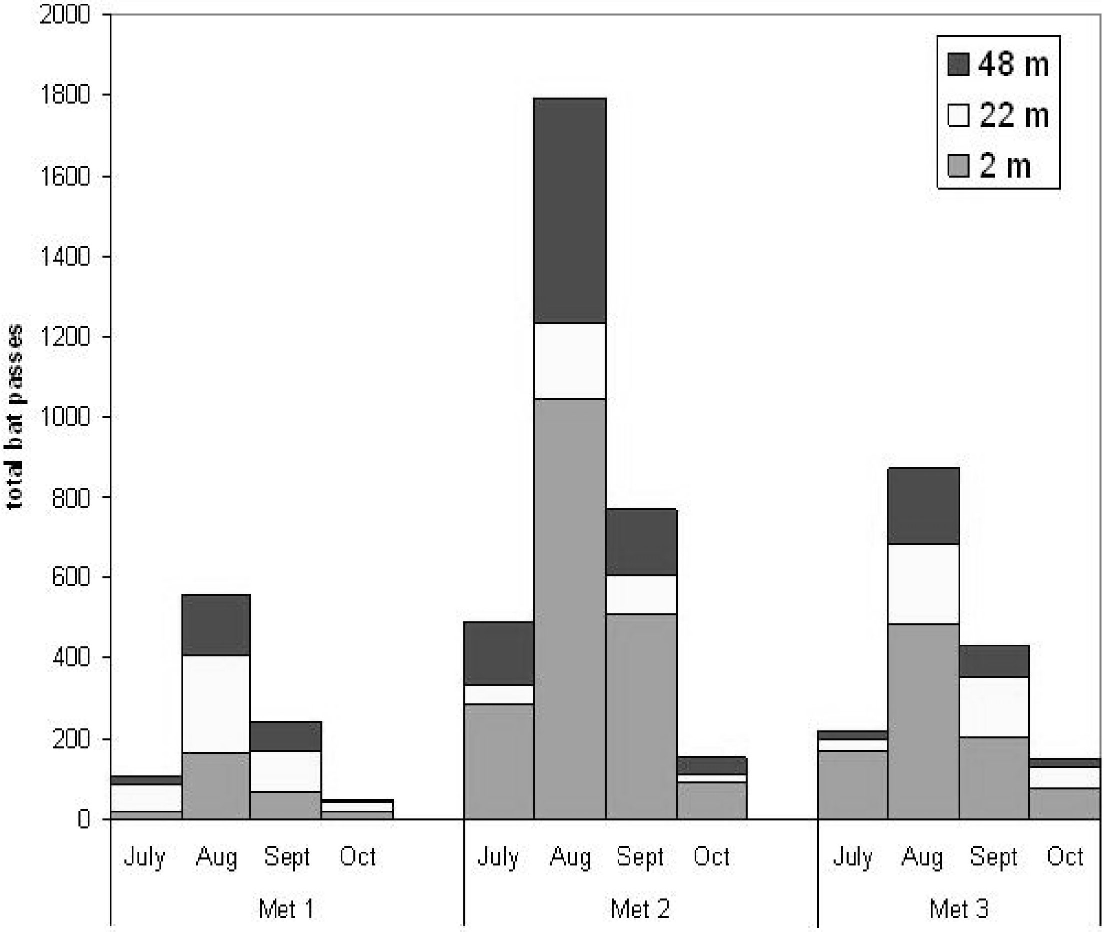


Figure 5. Total bat passes recorded by month and detector height (48 m, 22 m, and 2 m) at 3 MET towers. July recordings began on the 19th night.

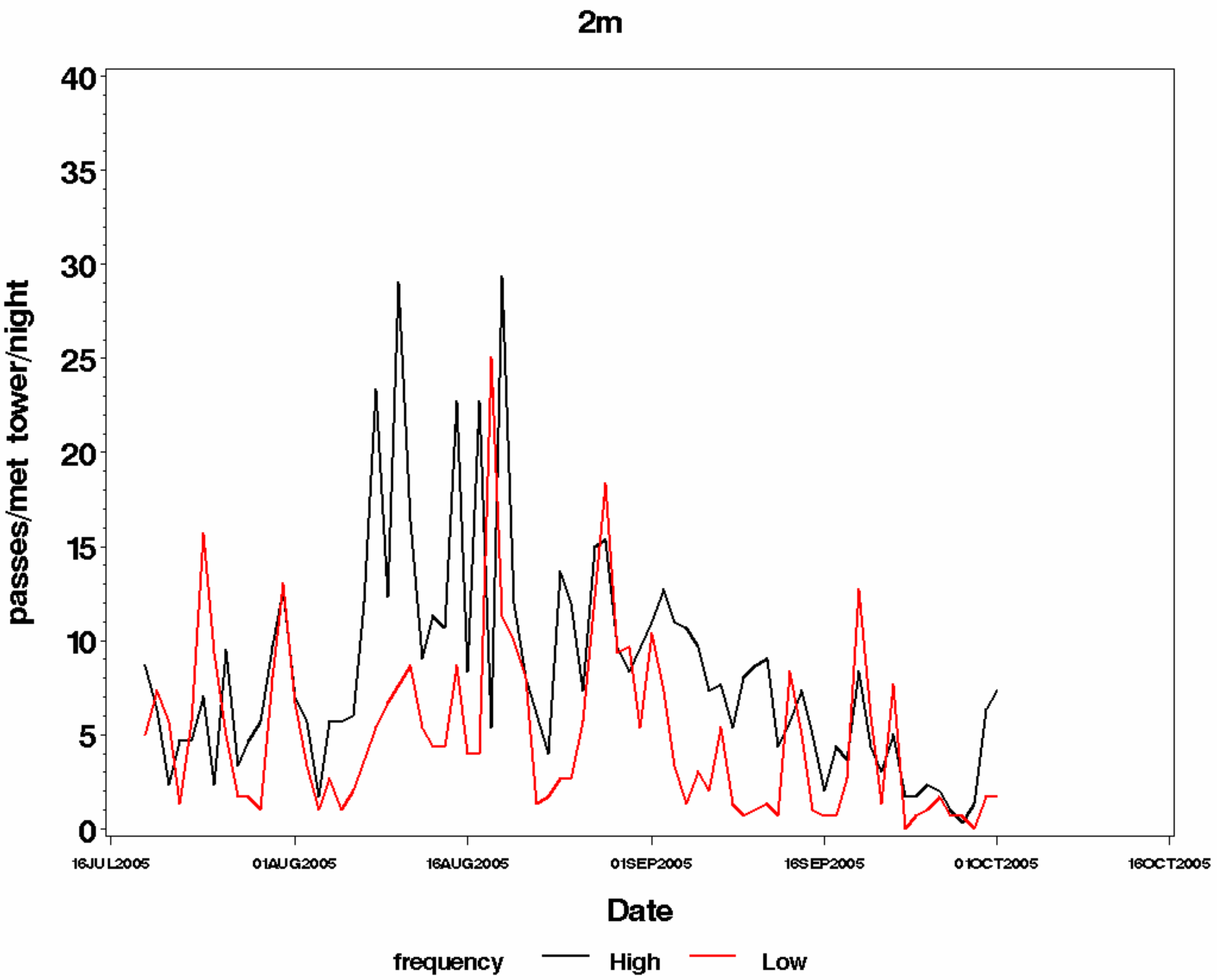


Figure 6. Average nightly bat pass activity of 3 Met towers for high and low frequency species groups recorded using acoustic detectors placed at ground level (2 m).

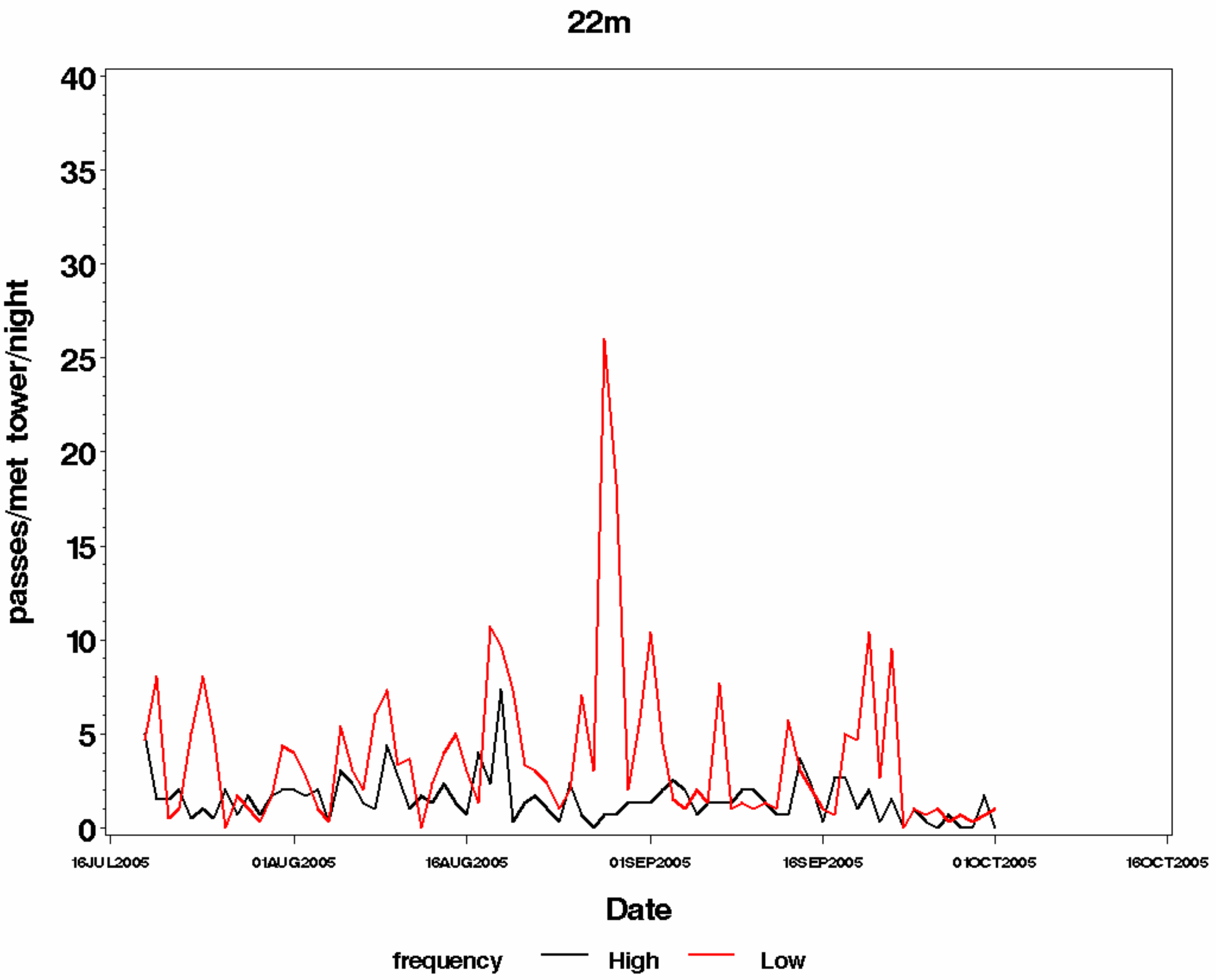


Figure 7. Average nightly bat pass activity of 3 Met towers for high and low frequency species groups recorded using acoustic detectors placed 22 m above ground.

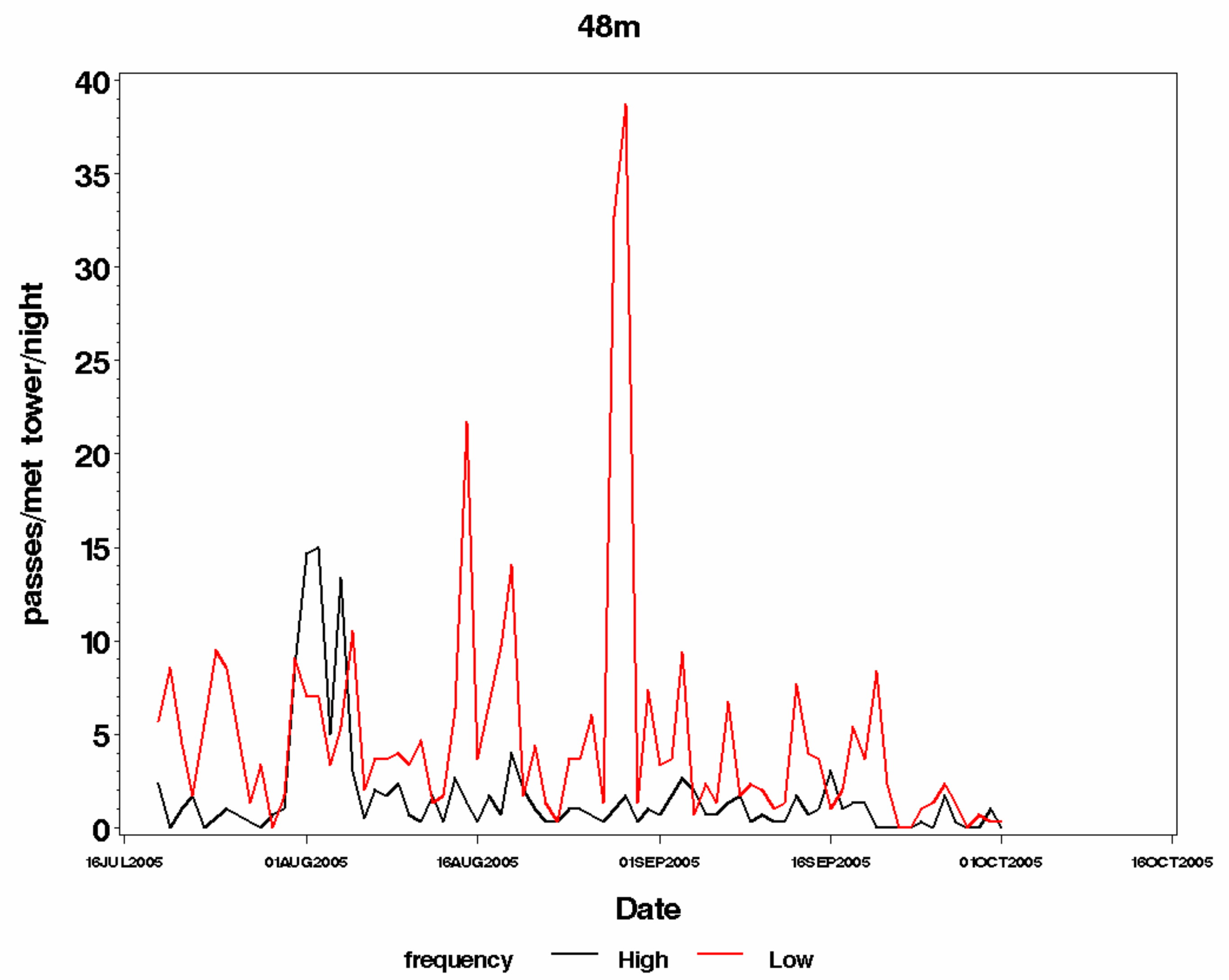


Figure 8. Average nightly bat pass activity of 3 Met towers for high and low frequency species groups recorded using acoustic detectors placed 48 m above ground.

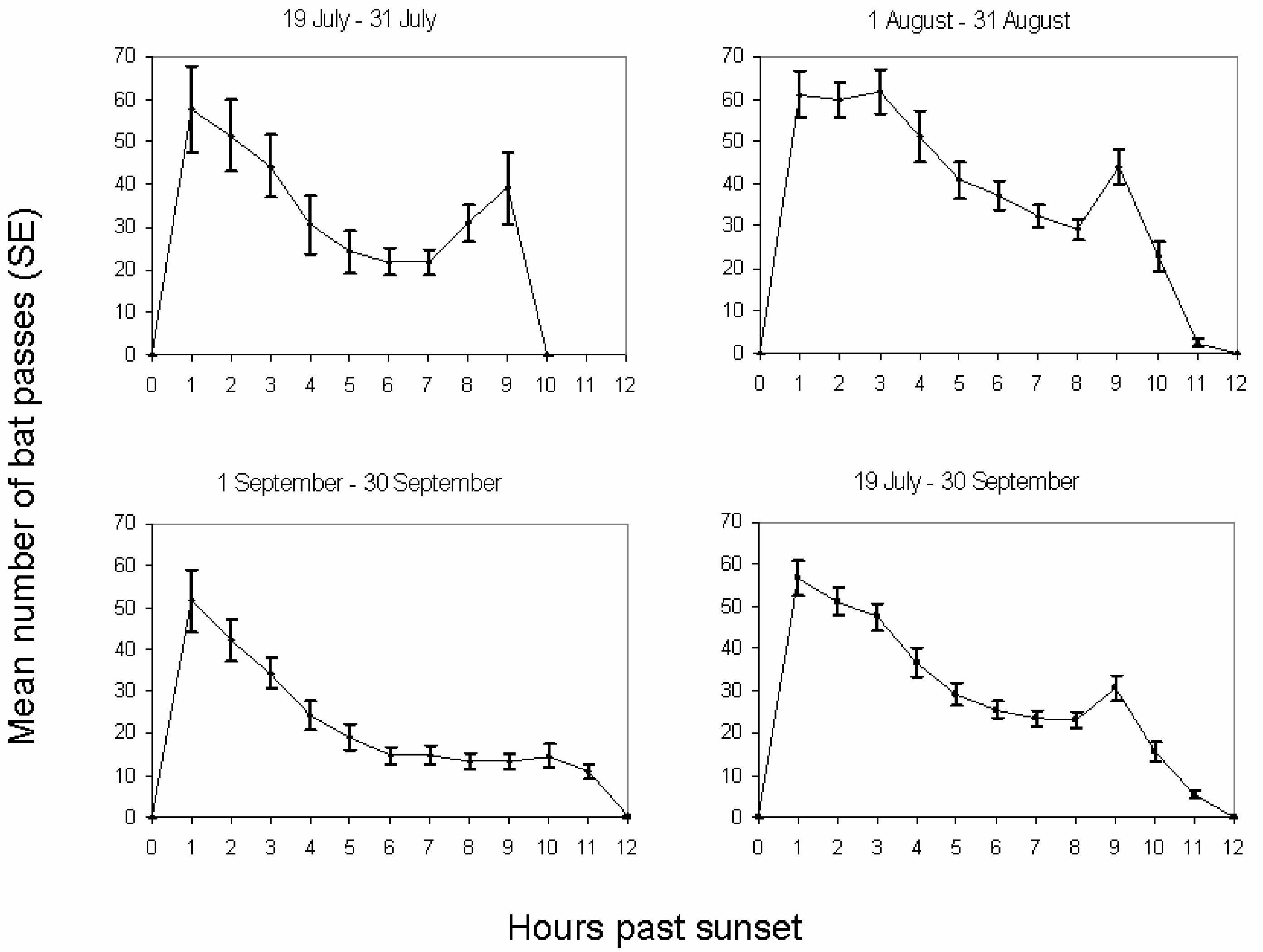


Figure 9. Mean number of bat passes (MET and mobile towers) in relation to sunset from mid-July through September 2005.

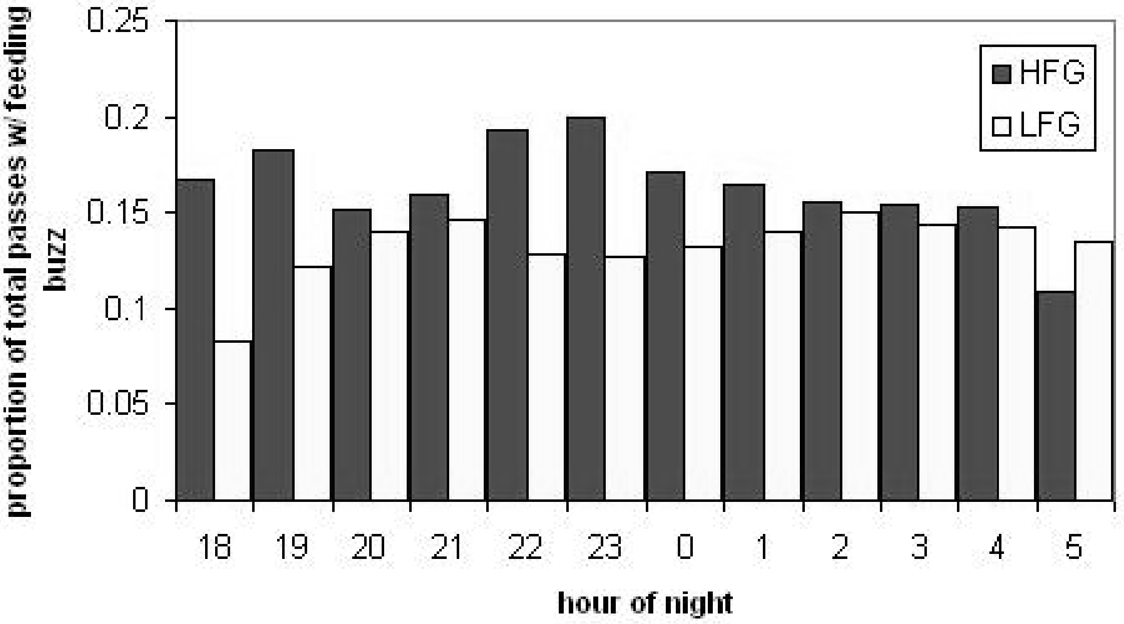


Figure 10. Proportion of total bat passes recorded from MET and mobile towers containing feeding buzzes by hour of night from mid-July through September 2005 separated by high (HFG) and low (LFG) frequency species groups.

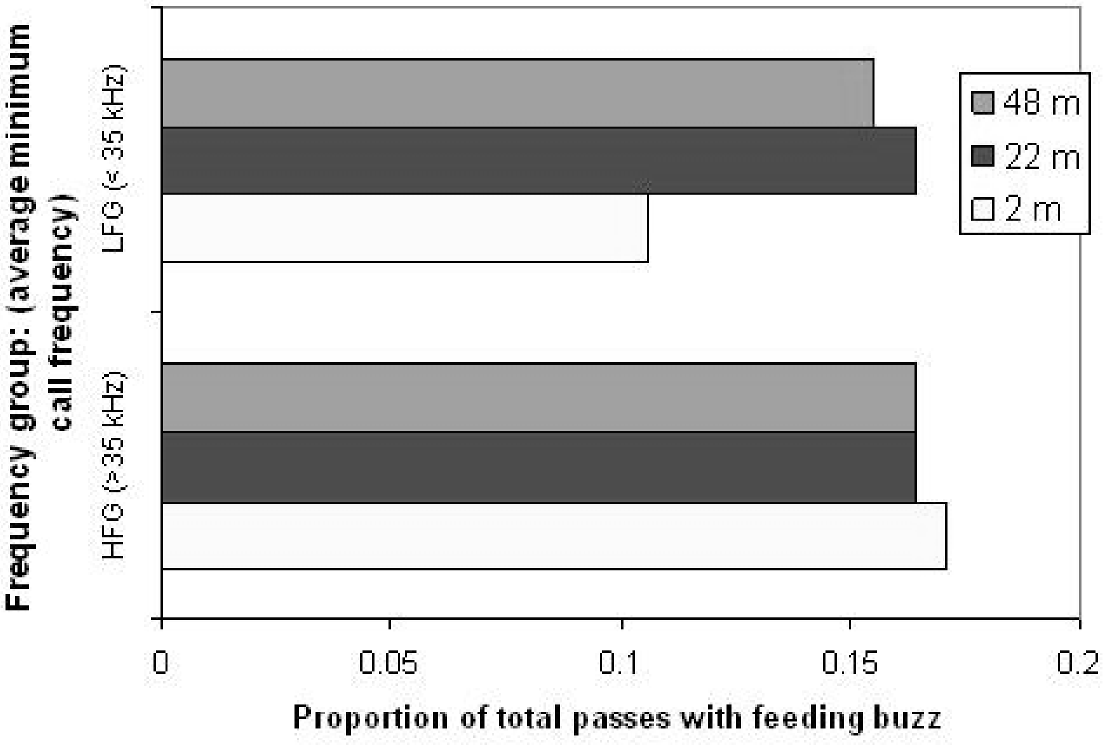


Figure 11. Proportion of total bat passes containing feeding buzzes at 3 detector heights (48 m values from 3 MET towers; 2 and 22 m values from MET and mobile towers) separated by high (HFG) and low (LFG) frequency species groups.

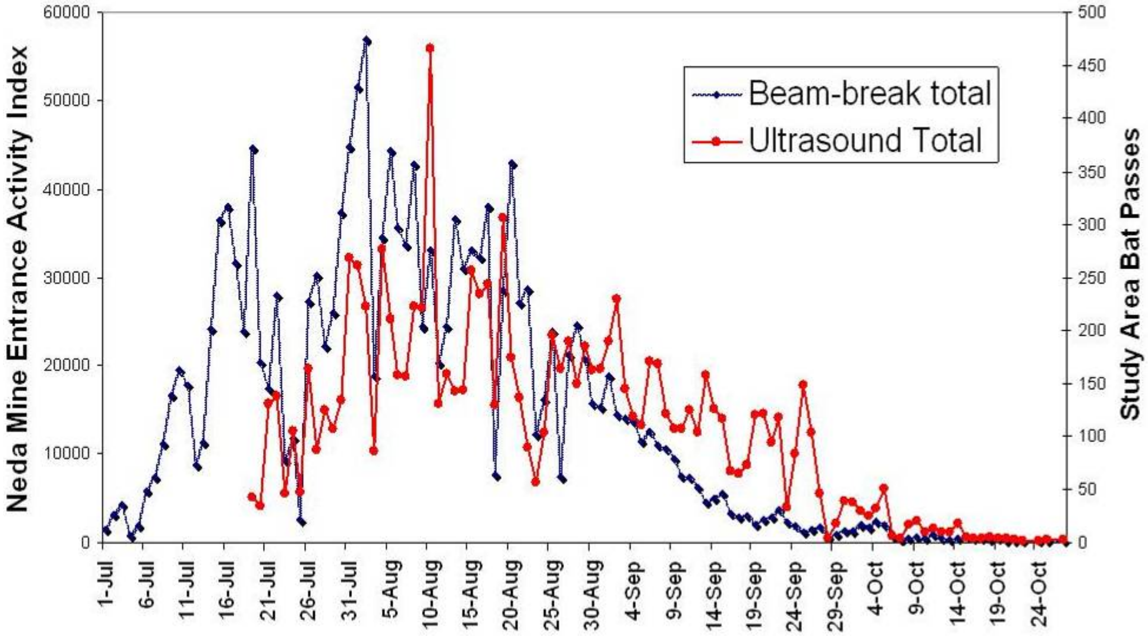


Figure 12. Combined Exit/Entrance bat activity at the Neda Mine (1 July through 31 October) as recorded by infrared-beam-break detectors located at each exit. Values are a relative index of bat activity (blue line) for the four species of bats returning to the mine for hibernation (primarily *Myotis lucifugus*). Acoustic data (red line) represent high frequency group species recorded within the study area.

Analysis of Bat Activity in Relation to Weather Variables and Detector Height

The current analysis addresses pre-construction activity and estimates activity rates and differences in activity patterns of two species' groups at three heights. In addition, the effects of temperature and wind speed on bat activity are assessed.

None of the models stood out as unequivocally best among the set (Appendix II). There were 29 models within 6 AIC units of the best model with a cumulative weight of 89% and another 11 brought the cumulative weight up to 95%. All four of the top models, within 2 AIC units of the best, including the best, included temperature, wind speed and the interaction of temperature with species group. Three of the top four models had one additional variable. Since the simplest model involving temperature, wind speed and the interaction of temperature with species group was also the best, results are interpreted based on it. The analysis of variance (ANOVA) table for this model is presented in Table 1.

Table 1. ANOVA table for the best model of the set. Significant p-values are < .05.

Source	DF	Chi-Square	p-value
date	1	6.80	0.0091
date*date	1	51.20	<.0001
height	2	93.74	<.0001
group	1	1.18	0.2778
height*group	2	99.57	<.0001
temp	1	45.15	<.0001
ws	1	13.39	0.0003
temp*group	1	4.90	0.0269

The two species groups tended to fly at different heights. Activity of high frequency bats was 1.8 to 7.3 times higher than that of low frequency bats at 2 m (Table 2). At higher altitudes, activity of low frequency bats was not detectably different than that of high frequency bats (Table 2). Activity of high frequency bats was estimated to be 3.2–5.5 times higher at 2 m than at 22 m, and 3.8–7 times higher at 2 m than at 48 m (Table 3). There was no detectable difference in activity at any height for the low frequency bats, nor at the higher altitudes (22 vs. 48 m) for the high frequency bats (Table 3).

Nighttime temperature during this study ranged from 7–26 ºC. The effect of temperature was very strong, and differed for the two groups. For each 1ºC increase in temperature, the activity rate of the high frequency group increased by 3–9% and the activity rate of the low frequency group increased by 7–13% (Table 2).

Nighttime wind speed during this study ranged from 1.0–9.6 m/s. Bat activity was strongly affected by wind speed. For each increase in wind speed of 1 m/s, the activity rate of bats was estimated to decrease by 4–13% (Table 2).

The relationship of bat activity to temperature for the two species groups at each of the three heights is graphed in Figures 13a and b., and the relationship of bat activity to wind speed for the two species groups at each of the three heights is graphed in Figures 14a and b.

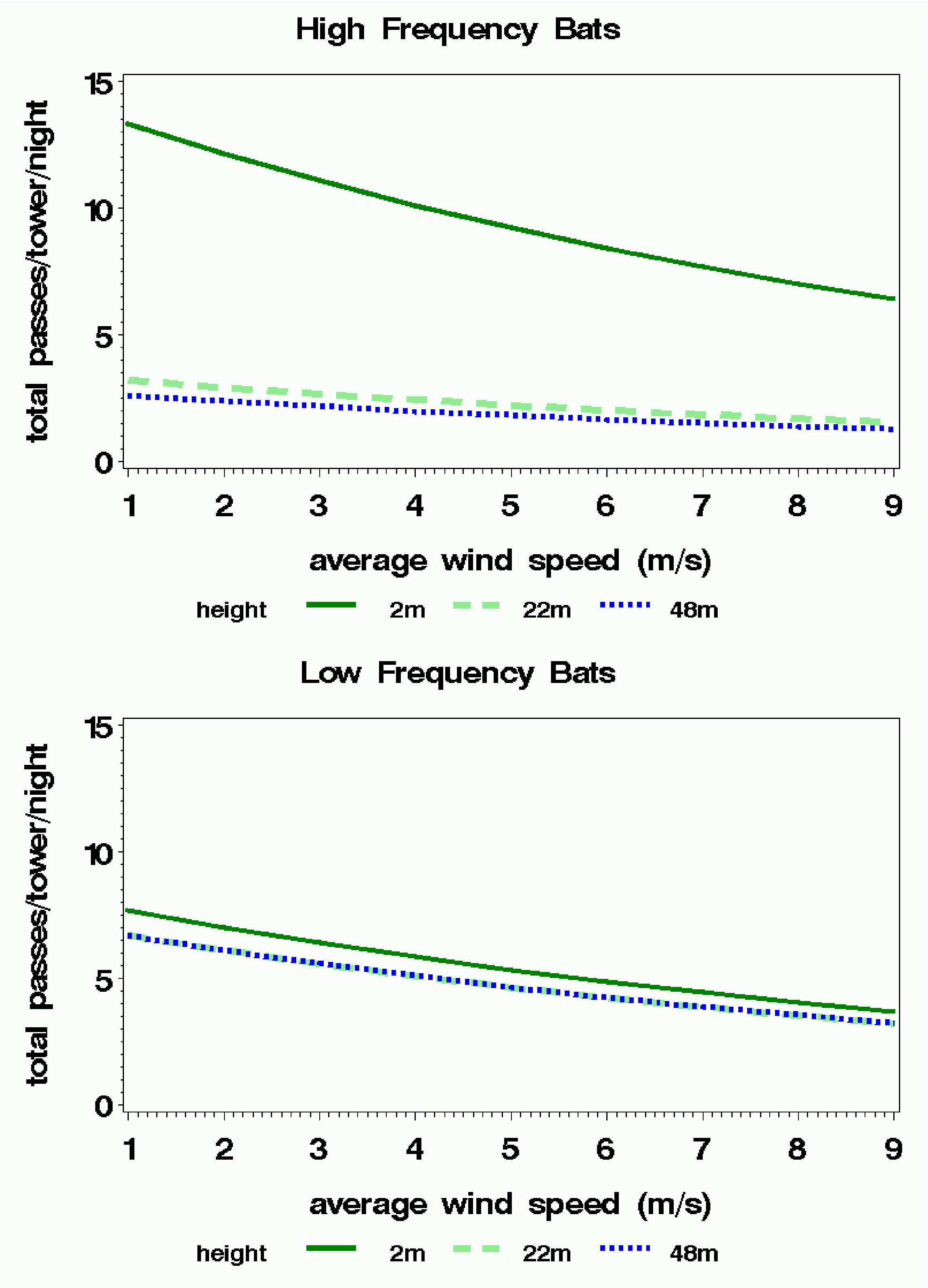
Table 2. Relative change in activity for each condition described. Lower and upper represent lower and upper limits of the 95% confidence interval of the estimate. Significant p-values are < .05.

Effect	change	lower	upper	Chi-Square	p-value
high vs. low, ht=2m	3.67	1.84	7.32	13.57	0.0002
high vs. low, ht=22m	1.01	0.51	2.02	0.00	0.9730
high vs. low, ht=48m	0.82	0.41	1.64	0.31	0.5761
wind speed effect	0.91	0.87	0.96	13.60	0.0002
temp effect, high freq	1.06	1.03	1.09	15.35	<.0001
temp effect, low freq	1.10	1.07	1.13	45.36	<.0001

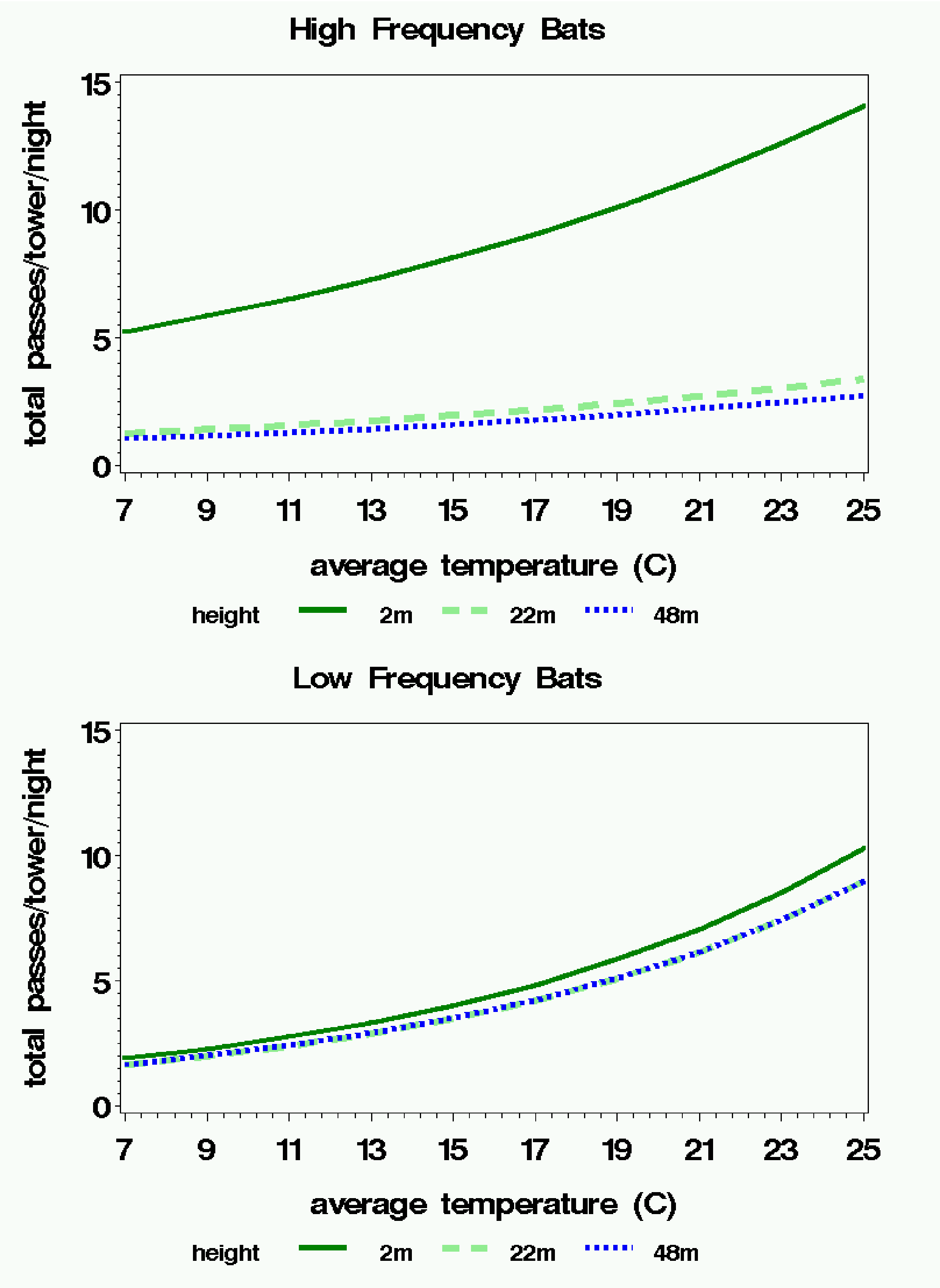
Table 3. Differences in activity at different sampling heights, by frequency group. Lower and upper represent lower and upper limits of the 95% confidence interval of the estimate. Significant p-values are < .05 (Bonferroni procedure for multiple comparisons).

Label	median	lower	upper	Chi-Square	p-value
2 vs. 22m, high freq	4.17	3.18	5.46	159.51	<.0001
2 vs. 48m, high freq	5.13	3.79	6.96	166.05	<.0001
22 vs. 48m, high freq	1.23	0.94	1.62	3.37	0.0666
2 vs. 22m, low freq	1.15	0.88	1.51	1.53	0.2156
2 vs. 48m, low freq	1.15	0.85	1.56	1.20	0.2738
22 vs. 48m, low freq	1.00	0.76	1.31	0.00	0.9930

Total bat activity was highest in mid August (Figure 15). Total bat activity increased with increasing temperature (Figure 16). Average wind speed was less than 5.4 m/s on 75% of the nights and the highest average wind speed recorded for a night was 9.6 m/s. Even at that level there was still some bat activity (Figure 17) in both species groups.



Figures 13a and b. Estimated median number of passes/tower/night at the average temperature (19º C) at three heights (Solid Green = 2 m, Dashed green = 22 m, Dotted Blue = 48 m) as a function of wind speed for high frequency bats (**a** on top) and low frequency bats (**b** on bottom).



Figures 14a and b. Estimated median number of passes/tower/night at the average wind speed (4 m/s) at three heights (Solid Green = 2 m, Dashed green = 22 m, Dotted Blue = 48 m) as a function of temperature for high frequency bats (**a** on top) and low frequency bats (**b** on bottom).

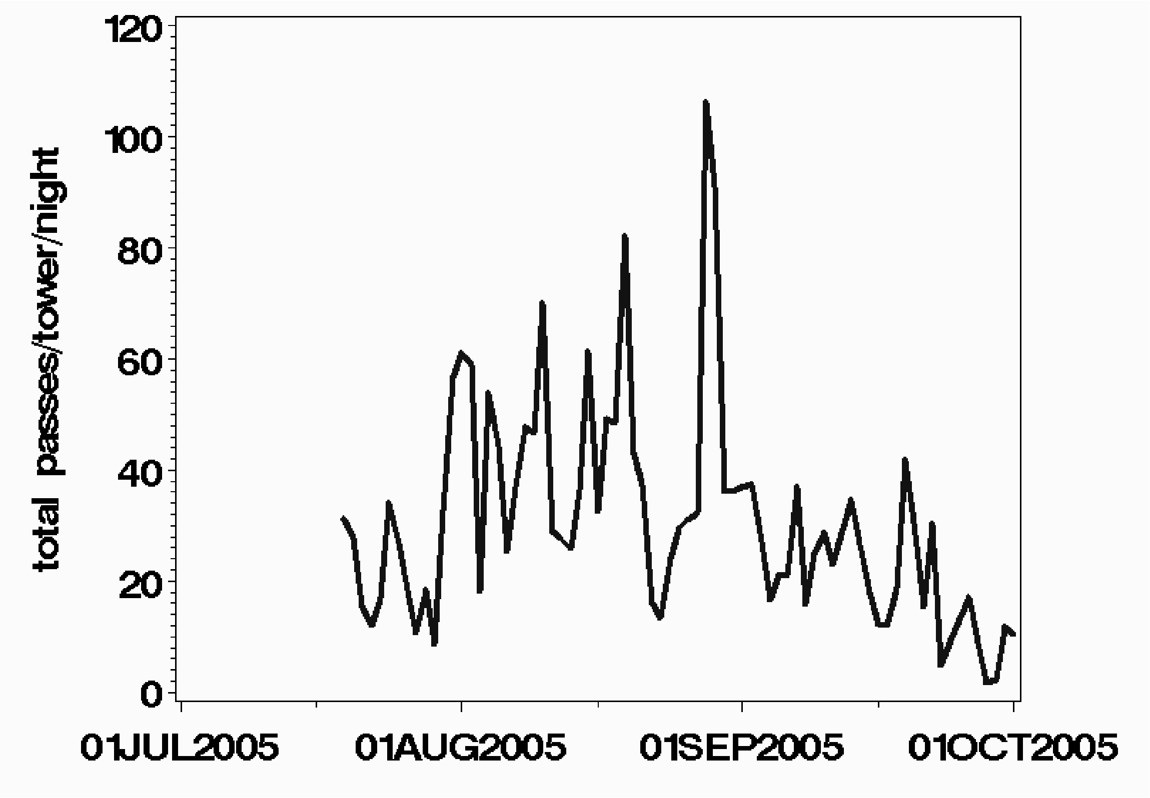


Figure 15. Total number of passes/night/tower by date.

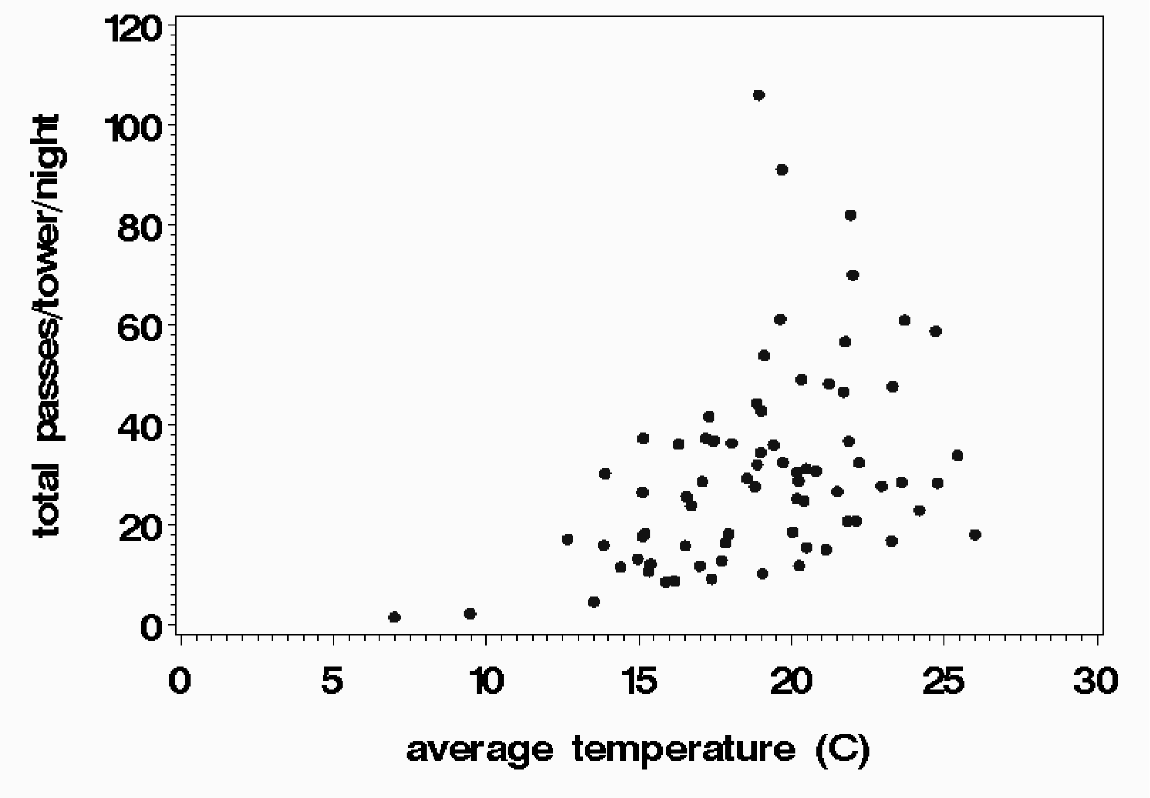


Figure 16. Total number of passes/night/tower by temperature (C).

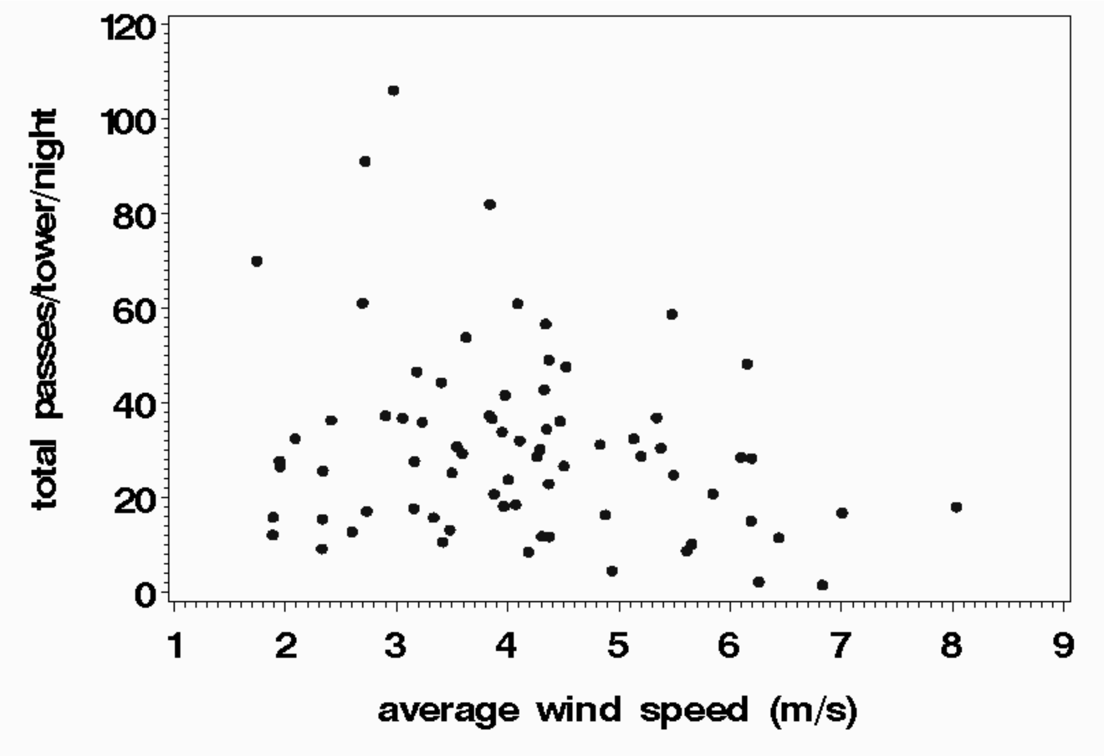


Figure 17. Total number of passes/night/tower by average wind speed (m/s).

Analysis of Bat Activity in Relation to Proposed Turbine Location, Proximity to Neda Mine and Habitat Features

As with the earlier analyses, this one addresses pre-construction activity and estimates activity rates and differences in activity patterns of two species groups as well as only the *Myotis* sp. at two heights. The high and low frequency species groups tended to fly at different heights at the Wisconsin site. Activity of high frequency bats was 1.8 to 7.3 times higher than that of low frequency bats at 2 m.

2 m, high and low frequency species groups.

Relative activity of high frequency bats decreased by between 5 and 28% for every kilometer increase in distance of a tower from the Neda Mine (Table 5).

The average relative activity at mobile towers for high frequency bats was about equal to that of the MET towers (95% CI: 0.88, 1.31) (Figure 18a) and for low frequency bats (95% CI: 0.91, 1.39) (Figure 18b) indicating that the MET towers were fairly representative for comparisons to correct for date and weather conditions.

None of the models of relative activity at 2 m stood out as unequivocally best among the set (Appendix IV). The best model, just under 2 delta units better than the null model, indicated that relative activity was related to distance to the mine in the high frequency group, but not the low frequency group (Table 4). Relative activity rates of high frequency bats decreased between 5 and 28% for each 1000 m increase in distance from the mine (Table 5). There was no detectable relationship of relative activity with distance from the mine for low frequency bats (Table 5).

Table 4. ANOVA table for the best model of the set. Significant p-values are < .05.

```
                   Num     Den
Effect              DF      DF    F Value    Pr > F
hilow                1      34       4.14    0.0497
distmine             1      34       2.98    0.0934
distmine*hilow       1      34       5.12    0.0301
```

Table 5. Percent of activity at any point relative to activity 1 km closer to the mine. Lower and upper represent lower and upper limits of the 95% confidence interval of the estimate.

```
  Label     median   Lower   Upper
High freq:   0.82    0.72     0.95
Low  freq:   0.96    0.82     1.13
```

<u>22m, high and low frequency species groups.</u>

None of the models of relative activity at 22 m was better than the null model (Appendix IV), indicating that relative activity was not detectably related to any of the environmental variables hypothesized (Table 6).

Table 6. Percent of activity at any point relative to activity 1 km closer to the mine. Lower and upper represent lower and upper limits of the 95% confidence interval of the estimate.

```
  Label       median   Lower   Upper
High freq:     0.90    0.77    1.05
Low  freq:     1.02    0.86    1.21
```

The average relative activity at mobile towers for high frequency bats was about equal to that of the MET towers (95% CI: 0.90, 1.29) (Figure 19a) and for low frequency bats (95% CI: 0.98, 1.44) (Figure 19b) indicating that the MET towers were fairly representative for comparisons to correct for date and weather conditions.

<u>2m, Myotis</u>

The average relative activity for *Myotis* bats at mobile towers was about equal to that of the MET towers (95% CI: 0.94, 1.33) (Figure 20a) indicating that the MET towers were fairly representative for comparisons to correct for date and weather conditions.

The model of relative activity at 2 m related to distance from the Neda Mine stood out as unequivocally best among the set (Appendix V). This model, just over 5 delta units better than the null model, indicated that relative activity of *Myotis* was related to distance to the mine ($F_{1,34} = 8.66$, P=0.0058). Relative activity of *Myotis* bats at 2 m decreased by between 6 and 28% for every kilometer increase in distance of a tower from the mine site (Figure 21.)

<u>22m, Myotis</u>

The average relative activity for *Myotis* bats at mobile towers was about equal to that of the MET towers (95% CI: 0.77, 1.08) (Figure 20b) indicating that the MET towers were fairly representative for comparisons to correct for date and weather conditions.

None of the models of relative activity at 22 m was better than the null model (Appendix V), indicating that relative activity was not detectably related to any of the environmental variables we measured ($F_{1,31} = 1.01$, P=0.32).

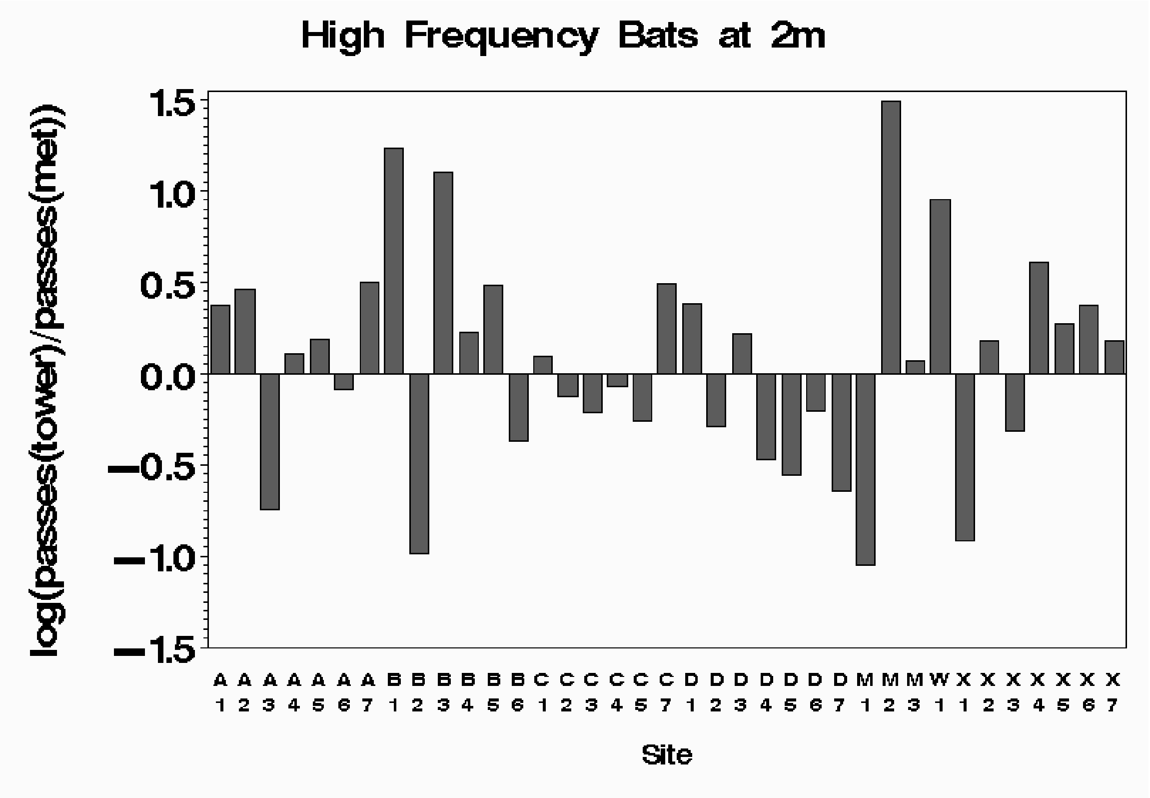


Figure 18a. Average log of relative activity (relative to MET tower average) of high frequency bats for each tower at 2m.

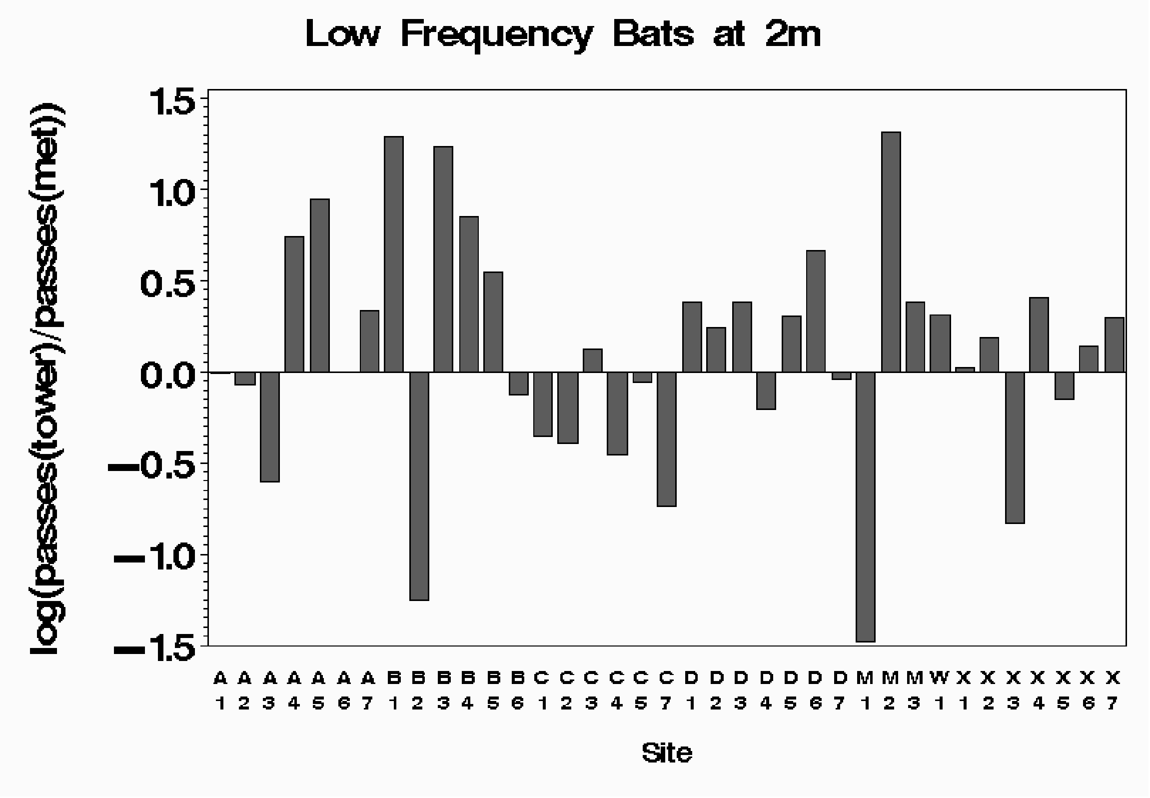


Figure 18b. Average log of relative activity (relative to MET tower average) of low frequency bats for each tower at 2m.

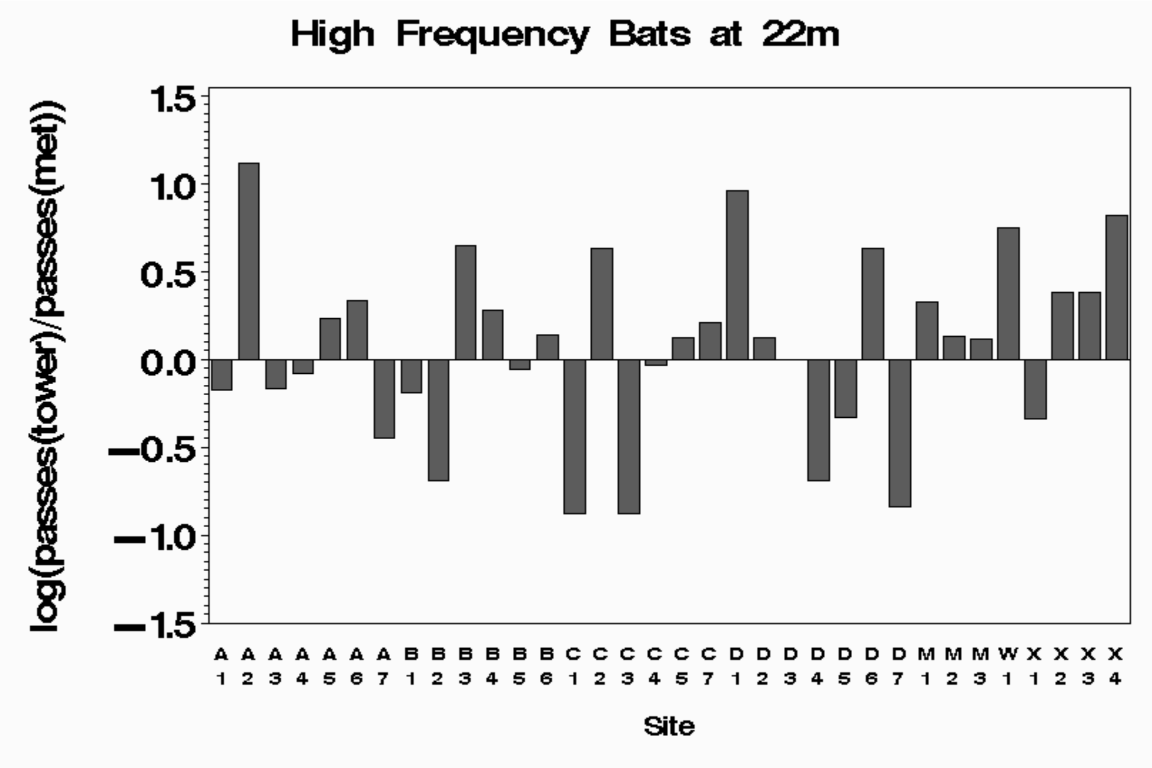


Figure 19a. Average log of relative activity (relative to MET tower average) of high frequency bats for each tower at 22m.

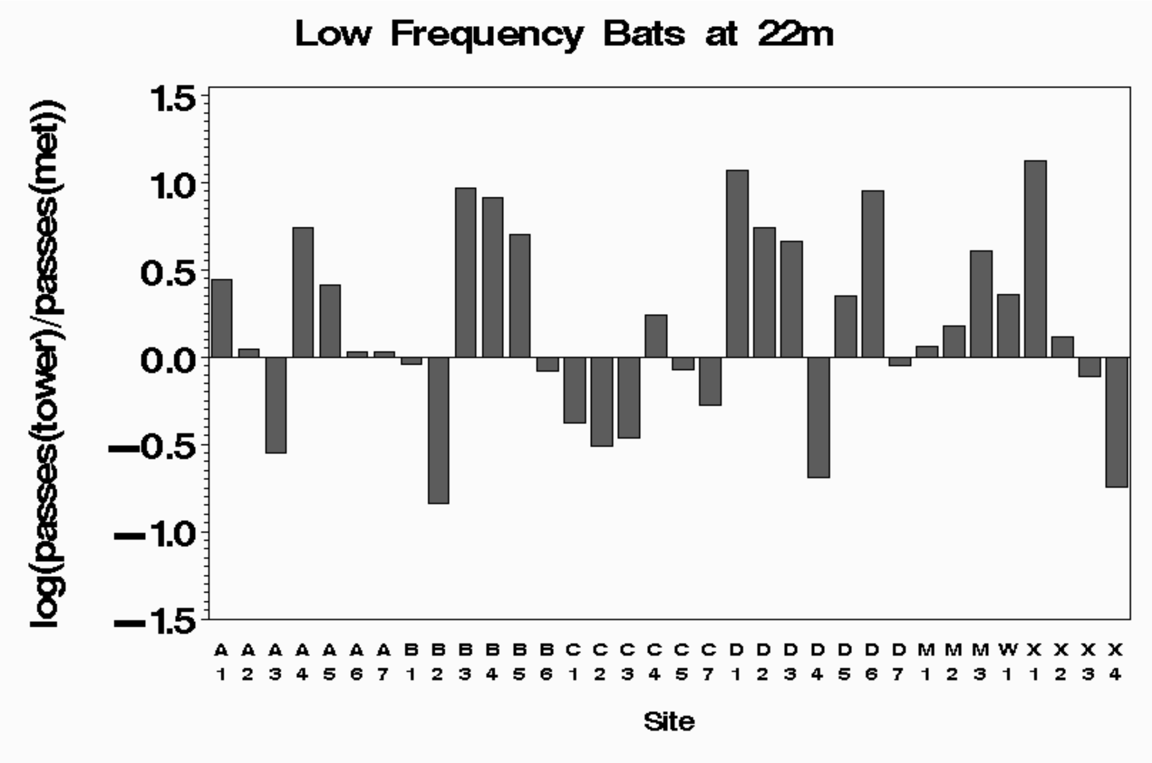


Figure 19b. Average log of relative activity (relative to MET tower average) of low frequency bats for each tower at 22m.

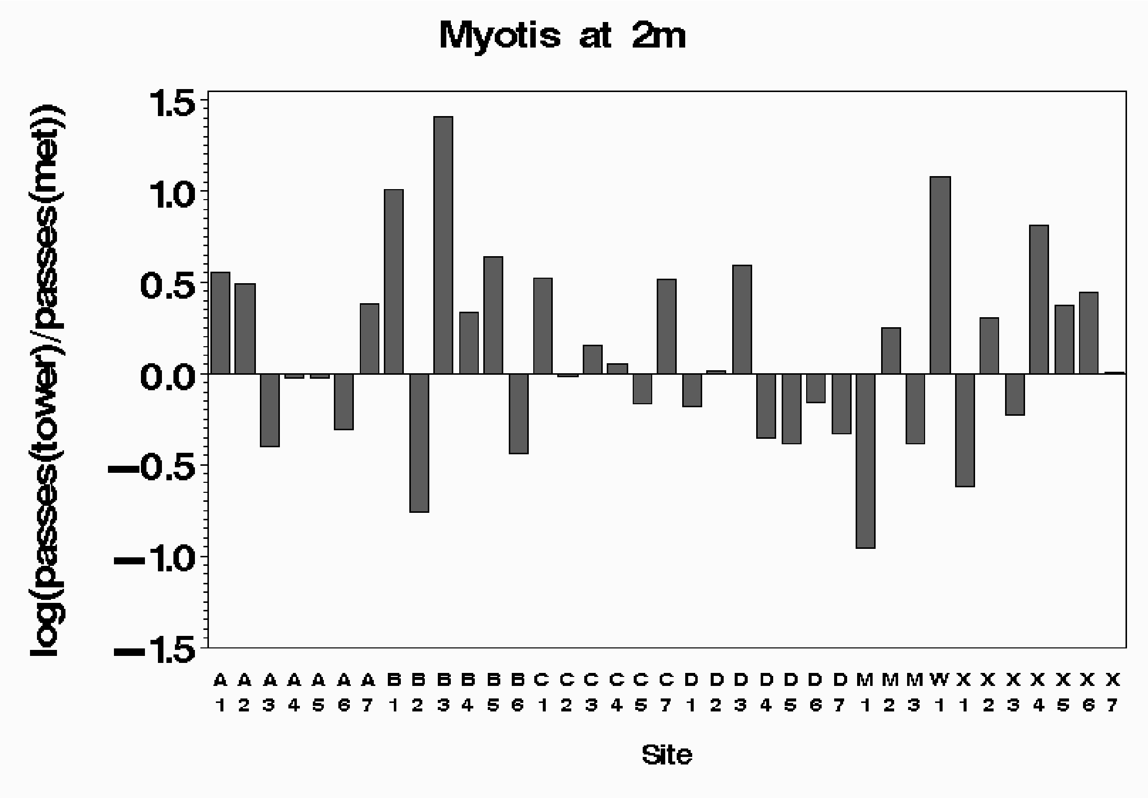


Figure 20a. Average log of relative activity (relative to MET tower average) of *Myotis* bats for each tower at 2m.

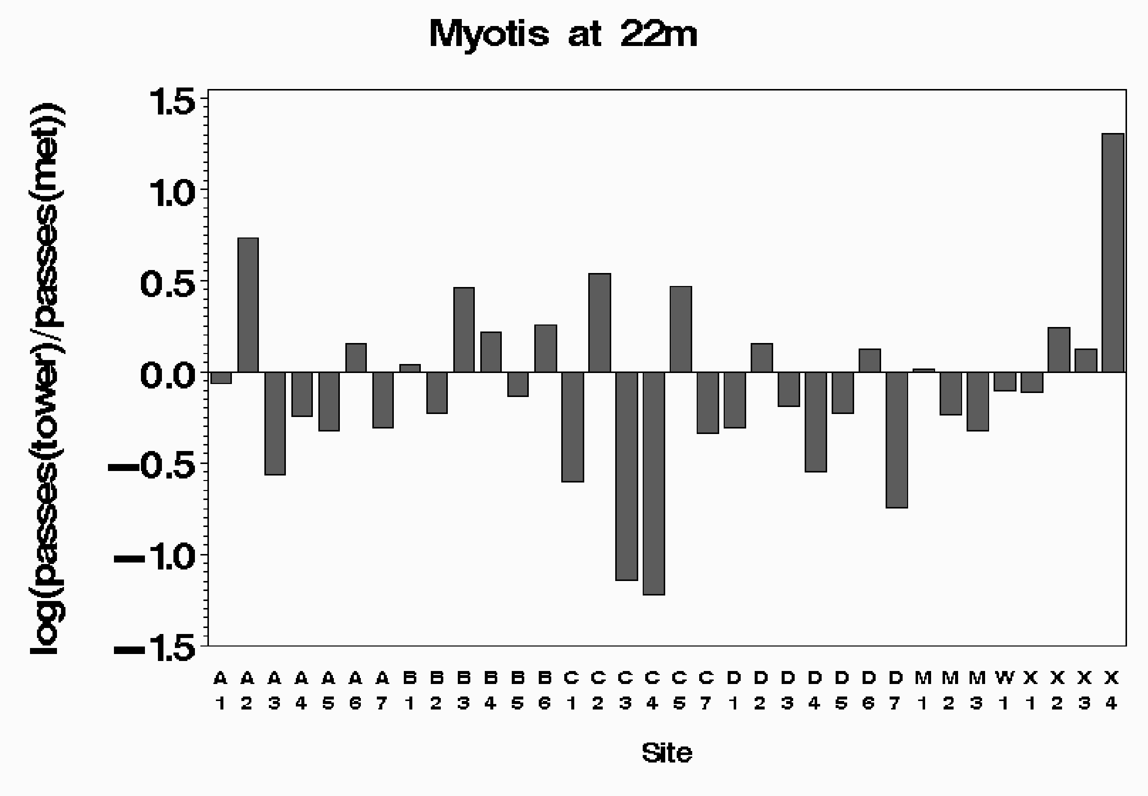


Figure 20b. Average log of relative activity (relative to MET tower average) of *Myotis* bats for each tower at 22m.

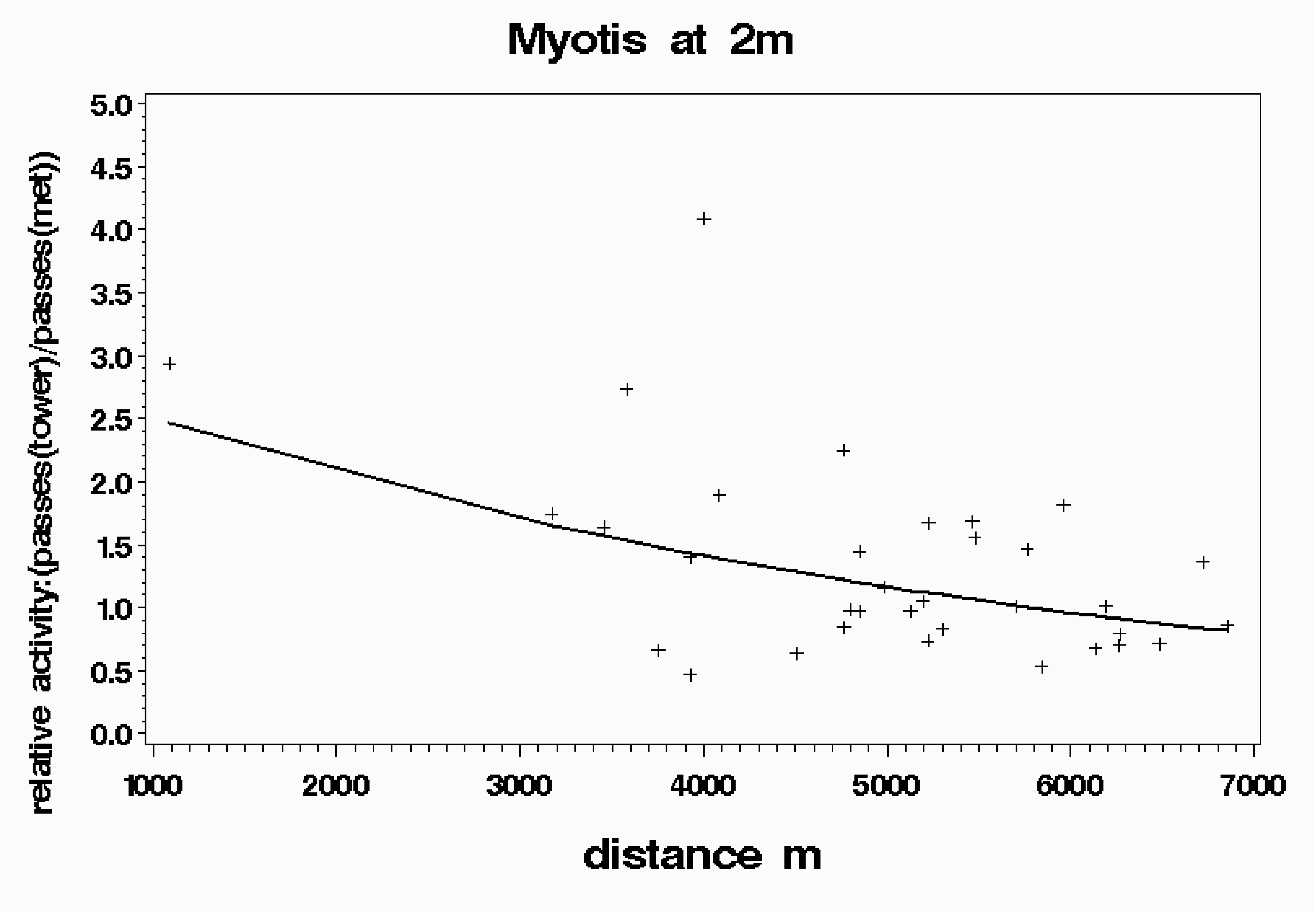


Figure 21. Relative activity (multiplicative factor relative to MET towers) of *Myotis* (+, and solid line) at 2m as a function of distance (m) of the tower from the mine.

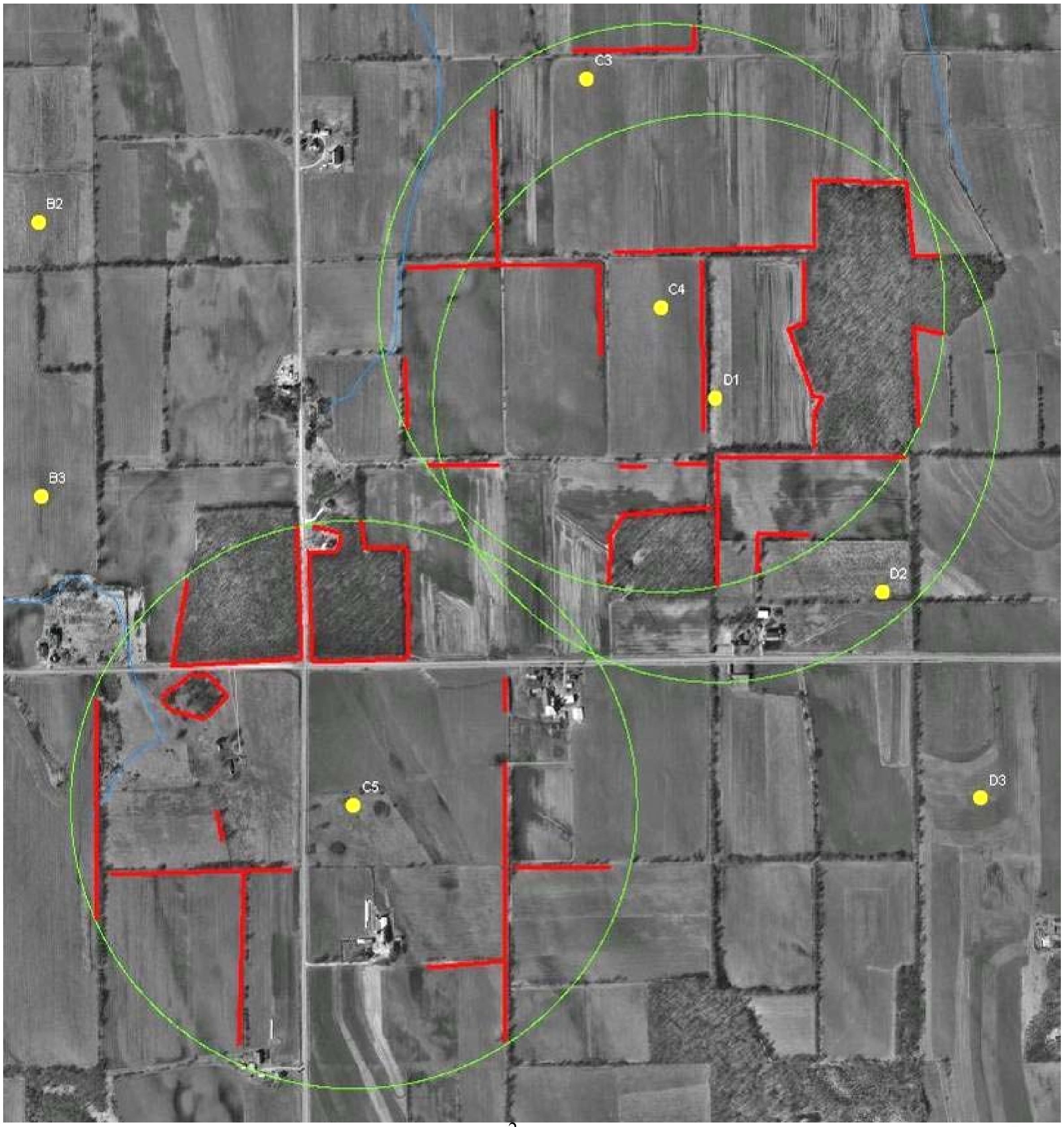


Figure 22. Locations C4 and C5 with 1 km^2 circles (green lines) used to quantify linear landscape features and forest patches surrounding each site. Red markings provide an example of the edge features measured using ArcMap software. Variables measured were: distance to nearest tree line or forest edge in 4 cardinal directions to quantify average distance to edge and nearest edge. Site D1 has a 1 km^2 circle displayed with no markings and shows a high degree of overlap with site C4 except distance to nearest tree line edge. Distance of each mobile and MET tower to Neda Mine as well as distance to nearest perennial water source was also measured.

DISCUSSION

Energy forecasters predict that world power consumption will increase by 50% by 2025, and wind energy is expected to provide 5% (~117,000 MW) of the U.S. energy needs (NREL 2006). More than 2,400 MW of wind energy were installed in 2005, with a projected 3,000 MW installed in 2006 (AWEA 2006). With the rapid expansion of wind energy development coupled with serious concern over bat fatalities at wind facilities (Tuttle 2004), reliable techniques for assessing the impact of wind power generation on bats is essential. Unfortunately, pre-construction estimates of activity have not been correlated with post-construction fatality, and the ability of various techniques, including acoustic monitoring, to predict fatality and evaluate risk remains unknown. Ultimately, if clear relationships between pre-construction activity and post-construction fatality can be established, pre-construction assessments of activity could provide useful assessments of risk to bats prior to development of wind facilities (Fiedler 2004).

While there have been relatively few studies investigating rates of bat fatality from which to draw solid conclusions applicable to most settings, the initial trend has been that migratory bats suffer the highest rates of fatal collision with turbines. Geographic location, topography, habitat characteristics, as well as seasonal changes in the bat community, relative abundance, and behavior likely contribute to a particular facility's level of risk to bats. The study area here represents a previously unstudied situation in that there is a large hibernaculum (primarily *Myotis lucifugus*) within proximity to the planned turbine locations. Whereas *Myotis* species generally represent a small proportion of the total found during fatality searches, we know of no studies or settings in which a wind facility was located near a major hibernaculum such as the Neda Mine. As more studies are conducted, we may find that certain species are affected differently depending on the local setting within the same geographic region, making generalized comparisons difficult. For example, during a study at the Buffalo Ridge Wind Farm in Minnesota, *Myotis lucifugus* made up 2% (3/151) of total carcasses found (Johnson et al. 2004). Approximately 300 km away to the southeast at the Top of Iowa WRA, 24% (18/75) of total carcasses found consisted of little brown myotis (Jain 2005). Using acoustic detectors at the base of turbines in the same Iowa study, the most commonly recorded species were classified as *Myotis* sp. and were likely little brown myotis (Jain 2005). In northeastern Wisconsin (approximately 175 km north northeast of the Neda Mine) where there are no known major hibernacula nearby, 8% (6/72) of carcasses found were *Myotis* species and 90% consisted of lasiurines and *Lasionycteris* (Howe et al. 2002).

Acoustic detectors have been used during post-construction monitoring, offering some insight on the use of detectors to predict fatality at turbines and identify an emerging need to sample activity well above ground level. Using 3 ground level detectors, no difference was found in the mean number of bat passes/detector night located at turbines with ($\bar{x}$ = 2.4) and without ($\bar{x}$ = 2.1) fatalities found the following day in Minnesota (Johnson et al. 2004). In Iowa, using 2 ground level detectors situated beneath turbines, no significant relationship between mortality and ultrasonic activity was found, however the report cautioned against inferring bat activity levels at higher altitudes based on data collected at ground level (Jain 2005). These findings suggest that predicting bat fatality from post-construction activity indices may not be possible for the species killed most frequently at wind facilities (see Johnson 2005) using bat detectors positioned at ground level. However, the aforementioned studies all noted that seasonal increases in bat activity closely coincided with the overall incidence of mortality at these sites.

Post-construction studies involving fatality searches coupled with acoustic detectors positioned at multiple heights above ground have yielded additional information. Using 4 detectors at 2 sites per night, a post-construction study in Tennessee (Fielder 2004) involved detectors at multiple heights and found no detectable difference between ground level and 15 m activity levels but did find higher ground level bat activity when compared to activity at nacelle height (approximately 70 m). Using a maximum of 3 detectors per night, Gruver (2002) concluded there was no difference between detectors at ground level and those elevated to a 15 m height as in Fiedler's (2004) study. Temporal patterns were found at the Buffalo Mountain wind farm in Tennessee indicating that bat activity levels generally were greater during nights when fresh killed bats were found during searches the next day, however, the predictive model used performed poorly (Fiedler 2004). In the same Tennessee study, two species (eastern red bat and hoary bat) were found proportionally more as turbine fatalities than were acoustically recorded, suggesting greater collision risk for these species than would be predicted with acoustic monitoring alone (Fiedler 2004). Though no detectors were above 15 m, hoary bats represented 88.1% of turbine fatalities at Foote Creek Rim, Wyoming, whereas they made up 7.8% of acoustical recordings (Gruver 2002). To determine whether a link exists between acoustic indices and bat fatality at existing turbines, future studies should include larger sample sizes across sites and at heights >15 m due to variation among species in flight altitude and the fact that searcher efficiency is usually well below 100% on any given day's search. Given these observations and the mixed findings from the Buffalo Mountain wind farm, future studies with more extensive and intensive investigation may identify stronger linkages between activity indices and bat mortality.

Temporal patterns of activity measured at our study area were similar to those gathered from other studies. We found that acoustic bat activity was generally highest from late July through mid September and declined through October. In Iowa, bat activity peaked in July and August, declined in September, and detection had mostly ceased by October (Jain 2005). In Tennessee, bat activity exhibited a seasonal peak from August to mid September during all three years of study (Fiedler 2004). Similar patterns were also reported in Minnesota (Johnson et al. 2004) and Wyoming (Gruver 2002). Association between timing of high activity and overall incidence of bat fatality previously reported (see Fiedler 2004, Johnson et al. 2004, and Jain 2005 for examples) suggest that temporal patterns of activity may prove useful for predicting the timing of fatality events in the future, but more studies across a wide range of landscape and environmental conditions are warranted.

Structural variation among habitats is an important consideration when inferring patterns of activity from acoustic data. Different species of bats respond to and use habitats with varying structural complexity (often referred to as clutter) differently (see Hayes 2003, Barclay and Kurta 2006, and Lacki et al. 2006 for recent reviews). Differences in wing morphology and maneuverability, as well as use of different echolocation frequencies and duty-cycles, influence the ability of bats to negotiate clutter and allow sympatric species to exploit different habitats. In general, maneuverable species of bats with small bodies and low wing-loading (e.g., most species of *Myotis*) are able to use habitats with higher levels of clutter than can less maneuverable species of bats with large bodies and high wing-loading (e.g., hoary bat). Bats also frequently use edge habitat for commuting and foraging (e.g., Furlonger et al. 1987; Limpens and Kapteyn 1991, Krusic et al. 1996, Grindal and Brigham 1999, Lacki et al. 2006). For example, the amount of bat activity in forests of British Columbia was higher along edges of clearcuts than either within the clearcut or within the uncut forest (Grindal and Brigham 1999).

Silver-haired bats, a relatively large species, are more active in clearcuts than in intact patches, whereas little brown myotis forage most extensively along the forest edge and northern long-eared bats (*Myotis septentrionalis*) forage most frequently within intact forest (Patriquin and Barclay 2003).

In our study, models selected as best explaining variation in bat activity did not include variables related to a tower's context to tree line or forest edge features on the landscape. In general, the mobile and MET towers were located in areas with low levels of clutter, which contrasts with the pre-construction study done in Pennsylvania (Arnett et al. 2006). Thus, no detectors were positioned directly at an edge or within a forest setting upon which comparisons to open areas could occur. Using ground level detectors positioned around the Neda Mine during the spring, a paired sample design of edge and open sites was used with results indicating a strong relationship to edge for both the high and low frequency species groups (Redell 2005). It is unclear to what degree these edge features are used by bats during the late summer and fall season at this study site. An acoustic study at a Minnesota wind farm found that activity decreased with increasing distance to woodlands but noted that results may have been a reflection of a high amount of activity at a few turbine sites relatively close to woodlands (within 100m) (Johnson 2004). In our study, the range of tower distances to nearest edge may not have been great enough to discern a difference. Furthermore, an edge effect is likely related to a threshold distance in response to a species effective range of echolocation (Verboom et al. 1999), insect concentrations, or wind speed (see Limpens and Kapteyn 1991, for description of edge use hypotheses) rather than a continuous decline in activity with increasing distance.

Accounting for spatial variation is important when collecting acoustic data at existing turbines or proposed turbine locations because different species of bats partition their use of habitats vertically, particularly in forests (e.g., Hayes and Gruver 2000, Jung et al. 1999, Kalcounis et al. 1999). Consequently, the assumption that activity data gathered below the rotor-swept area represents risk of bats in the rotor-swept area may be unjustified for some bat species and certain landscape and habitat conditions. Reynolds (2006) noted that large, migratory events of different species may be missed without sampling into the rotor-swept area. However, it remains to be determined if vertical acoustic sampling into the rotor-swept area increases predictability of fatality events for different species and groups of species of bats. The few acoustic studies that have employed vertical arrays of detectors that reach into the rotor-swept zone appear to reflect an emerging pattern of more low frequency echolocating bats detected at higher altitudes and the reverse for high frequency bats (Reynolds 2006, Arnett et al. 2006). While the high frequency bats in our study held a similar pattern with higher activity associated with lower altitudes, activity for the low frequency group was not detectably different at any of the three heights sampled.

We found that bat activity generally increased with increasing temperature and decreased as wind speed increased. Other acoustic monitoring studies at existing and proposed wind facilities have reported similar results (e.g., Fiedler 2004, Arnett et al. 2006, Reynolds 2006). Strong winds can influence insect abundance and activity, which in turn influences bat activity and bats are known to suppress their activity during periods of rain, low temperatures, and strong winds (Erkert 1982, Erickson and West 2002). Wind speed and direction were found to have an affect on habitat use for *Lasiurus cinereus* and *Lasionycteris noctivagans* with higher activity associated on the lee side of a ridge (Barclay 1985). In the Netherlands, pipistrelle bat foraging and commuting activity was concentrated on the leeward side and closer to tree lines as wind speed increased (Verboom and Spoelstra 1999). These patterns generally corroborate recent studies of bat fatality and the relationships with weather. At Buffalo Mountain in Tennessee, a negative relationship was found between bat fatality and wind speed, wind speed difference, and temperature, and a relationship with wind direction (Fiedler 2004). The relationship with wind direction indicated that the further wind direction was from southwest (the prevailing wind direction) the more likely a fatality event was to occur, perhaps due to more northerly winds associated with storm fronts and/or conditions that are conducive for bat migration (Fiedler 2004). The majority of bats killed at the Meyersdale, Pennsylvania and Mountaineer, West Virginia facilities were reported to occur on low wind nights, and fatalities tended to increase just before and after the passage of storm fronts (Kerns et al. 2005). These emerging patterns hold promise for improving our ability to assess risk and better predict factors influencing the timing of fatality events. Modeling the relationships between bat activity and weather variables will be an important component of future studies designed to assess risk of bat fatality at wind facilities.

Feeding type activity was identified at all heights in this study and throughout all hours of the night for both species groups. While a direct comparison among studies is considered subjective due to the variation among researchers in classifying feeding buzzes (Hayes 2000), a review of values stated in the literature found 8 studies of Vespertilionids reporting proportion of passes containing feeding buzzes (Brigham et al. 1997; Furlonger et al. 1987; Grindal & Brigham 1999; Grindal 1998; Hogberg et al. 2002; Menzel et al. 2002; Vaughan et al. 1997; Walsh & Harris 1996) and values ranged from 7%-22.3% giving an average among studies of 16.1%. While this study was within the range noted above (15.1% of total passes containing feeding buzzes), we cannot rule out the possibility that some of the feeding buzzes were associated with bats investigating the guy wires or towers themselves rather than pursuit and attempts at capture of flying insects. For example, buzzes similar to feeding pursuits were observed when bats were maneuvering around small wires or just before landing (Griffin et al 1960) which emphasizes that feeding buzzes should be viewed as an index rather than an absolute value. However, given the proximity to the mine and time of year when bats are building energy reserves, it is likely that many of these buzzes were associated with feeding attempts.

While the spring data on the landscape surrounding the Neda Mine showed a consistent spatial and temporal pattern for two consecutive years (Redell 2005), the behavioral differences in bat activity are expected to result in higher spatial variability during the fall at this site. That is, with little to no spring foraging activity detected, and individual bats having nightly departures with no corresponding returns to the Neda Mine during the April and May migration-dispersal period, bat activity appeared to be associated with directional travel of colonies to their summer roost sites. On the other hand, fall behavior is likely associated with individuals having multiple nights of activity on the surrounding landscape while they forage to build energy reserves for winter hibernation. Besides weather and habitat variables, spatial and temporal variability in the fall is likely tied to patterns of nightly and local changes in insect abundance (both vertical and horizontal distributions). When compared with spring bat activity, behavioral differences during the fall, i.e., building fat reserves, may involve multiple exposure risk of collision with turbines for individual bats using the Neda Mine. In addition, there is no clear evidence indicating that the foliage roosting bat migration during fall occurs as a rapid event as with birds. While nocturnal bird migration is not associated with aerial feeding, there is foraging activity associated with both frequency groups of bats in this study. Though still unknown, instead of a rapid long distance journey, the foliage roosting bats migration could involve a relatively slow southward movement while opportunistically taking advantage of food resources during times of suitable conditions.

SCOPE, LIMITATIONS, and NEXT STEPS

This study was conducted at one proposed wind energy facility located within an agricultural landscape in the Midwestern United States, and statistical inferences are limited to this site. We believe our findings are not directly comparable to most other agricultural settings due to the proximity of the site to the Neda Mine bat hibernaculum which is one of the largest hibernation sites in the Midwest and certainly influenced the high frequency species group activity levels in the study. However, we do believe that our findings related to decreasing activity levels with increased distances from a hibernation site, relationship of frequency groups and elevation, relationships with weather variables, and general timing are relevant to agricultural areas with similar species composition. We caution that this portion of our study encompasses the mid-summer-fall period and does not represent a full period when bats are active (generally late March through October). Refer to spring activity data collected near the Neda Mine (Redell 2005) for a study conducted during the months of April and May, but note the difference in study design in that those data were from 16 concurrent detectors rotated among 32 sites positioned at ground level.

Our analyses are exploratory, in part because so little data exist upon which to develop a priori, confirmatory hypotheses and associated candidate models. The current analysis estimates activity rates and differences in activity patterns of two species groups (high and low frequency), in open habitat at three heights. We anticipate development of more species and species-specific group models in the future. As wind direction may affect migratory bat behavior and could be an important predictor of activity and therefore relevant for mitigation options, we plan to include it as a possible factor in future analyses.

This study consists of one mid-summer-fall season of data conducted prior to construction of the turbines. We recognize the uncertainty related to placing strong inference on one year's data without understanding the year to year variability. While the study in Pennsylvania (Arnett et al. 2006) will help illuminate the year to year variability associated with fall bat activity, the yearly spatial and temporal variability associated with cave bat species behavior and activity in proximity to a large hibernation site remains in question.

High variation in levels of activity has consequences with respect to sampling design and level of effort required to obtain accurate estimates of activity; as fewer nights are sampled, there is an increased probability of obtaining mean estimates of activity that differ greatly from those calculated from large datasets (Hayes 1997). Low-intensity sampling could result in under- or over-estimates of activity and the most precise and accurate estimates will likely come from intensive sampling efforts (Hayes 1997). Unfortunately, the cost of intensive sampling can often exceed the project budget (Fenton 2000). But if acoustic monitoring is to be used to predict bat fatality at wind facilities, accurate measures of activity and fatality, both before and after construction are critical. In our future analyses, we will evaluate the trade-offs of reduced sampling and hence, reduced costs, on the accuracy and precision of our estimates of bat activity and fatality, with the ultimate goal of optimizing sampling designs and data requirements for employing acoustic monitoring to predict bat fatality at wind facilities.

Turbine construction for this site is tentatively scheduled for spring-summer 2007, after which two years of post-construction fatality data will be gathered to compare with pre-construction activity levels.

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Appendix I. Description of models compared in this study.

We compared a total of 77 models using QAIC as described by Burnham and Anderson (2002). All models included the design factors (species group and height) and their interaction as well as julian date and the quadratic effect of julian date. In addition, the following models were proposed and compared. Models 100 through 112 model temperature and wind speed as having the same effect regardless of species group or height. Models 201 through 232 allow the effects of temperature and/or wind speed to vary by species group. Models 301 through 332 parallel models 201 through 232, but allow the effects of temperature and/or wind speed to vary by height rather than species group.

Model #	Description	Variables
100	Null model, no effect of temp or wind speed	
101	linear effect of temperature	temp
102	linear effect of wind speed	ws
103	linear effect of temperature and wind speed	temp ws
104	linear effect of temperature and wind speed and interaction of the two	temp ws temp*ws
105	linear and quadratic effect of temperature	temp temp*temp
106	linear and quadratic effect of wind speed	ws ws*ws
107	linear effect of temperature and wind speed and quadratic effect of temperature	temp ws temp*temp
108	linear effect of temperature and wind speed with interaction of the two, and quadratic effect of temperature	temp ws temp*ws temp*temp
109	linear effect of temperature and wind speed and quadratic effect of wind speed	temp ws ws*ws
110	linear effect of temperature and wind speed with interaction of the two, and quadratic effect of wind speed	temp ws temp*ws ws*ws
111	linear and quadratic effect of temperature and wind speed	temp ws temp*temp ws*ws
112	linear and quadratic effect of temperature and wind speed, and interaction of the two	temp ws temp*ws temp*temp ws*ws
201	linear effect of temperature differs between the two species groups	temp temp*group
202	linear effect of temperature and wind speed, but the linear effect of temperature differs between the two species groups	temp ws temp*group

203	linear effect of temperature and wind speed, but the linear effect of wind speed differs between the two species groups	temp ws ws*group
204	linear effect of temperature and wind speed, but the linear effect of each differs between the two species groups	temp ws temp*group ws*group
205	linear effect of temperature and wind speed, with interaction of the two, but the linear effect of temperature differs between the two species groups	temp ws temp*ws temp*group
206	linear effect of temperature and wind speed, with interaction of the two, but the linear effect of wind speed differs between the two species groups	temp ws temp*ws ws*group
207	linear effect of temperature and wind speed, with interaction of the two, but the linear effect of both temperature and wind speed differs between the two species groups	temp ws temp*ws temp*group ws*group
208	linear effect of temperature and wind speed, with interaction of the two, all of which differ between the two species groups	temp ws temp*ws temp*group ws*group temp*ws*group
209	linear and quadratic effect of temperature and the linear effect differs between the two species groups	temp temp*temp temp*group
210	linear effect of temperature and wind speed and quadratic effect of temperature and the linear effect of temperature differs between the two species groups	temp ws temp*temp temp*group
211	linear effect of temperature and wind speed and quadratic effect of temperature and the linear effect of wind speed differs between the two species groups	temp ws temp*temp ws*group
212	linear effect of temperature and wind speed and quadratic effect of temperature and the linear effects of both temperature and wind speed differ between the two species groups	temp ws temp*temp temp*group ws*group
213	linear effect of temperature and wind speed, with interaction of the two, and quadratic effect of temperature and the linear effect of temperature differs between the two species groups	temp ws temp*ws temp*temp temp*group

214	linear effect of temperature and wind speed, with interaction of the two, and quadratic effect of temperature and the linear effect of wind speed differs between the two species groups	temp ws temp*ws temp*temp ws*group
215	linear effect of temperature and wind speed, with interaction of the two, and quadratic effect of temperature and the linear effects of both temperature and wind speed differ between the two species groups	temp ws temp*ws temp*temp temp*group ws*group
216	linear effect of temperature and wind speed, with interaction of the two, all of which differ between the two species groups, and quadratic effect of temperature	temp temp*temp ws temp*ws temp*group ws*group temp*ws*group
217	linear effect of wind speed differs between the two species groups	ws ws*group
218	linear and quadratic effect of wind speed and the linear effect of wind speed differs between the two species groups	ws ws*ws ws*group
219	linear effect of wind speed and temperature and quadratic effect of wind speed and the linear effect of wind speed differs between the two species groups	temp ws ws*ws ws*group
220	linear effect of wind speed and temperature and quadratic effect of wind speed and the linear effect of temperature differs between the two species groups	temp ws ws*ws temp temp*group
221	linear effect of wind speed and temperature and quadratic effect of wind speed and the linear effects of both wind speed and temperature differ between the two species groups	temp ws ws*ws ws*group temp*group
222	linear effect of wind speed and temperature, with interaction of the two, and quadratic effect of wind speed and the linear effect of wind speed differs between the two species groups	temp ws ws*temp ws*ws ws*group
223	linear effect of wind speed and temperature, with interaction of the two, and quadratic effect of wind speed and the linear effect of temperature differs between the two species groups	temp ws temp*ws ws*ws temp*group

224	linear effect of wind speed and temperature, with interaction of the two, and quadratic effect of wind speed and the linear effects of both wind speed and temperature differ between the two species groups	temp ws temp*ws ws*ws ws*group temp*group
225	linear effect of wind speed and temperature, with interaction of the two, all of which differ between the two species groups, and quadratic effect of wind speed	temp ws temp*ws ws*ws ws*group temp*group ws*temp*group
226	linear and quadratic effect of wind speed and temperature, and the linear effect of temperature differs between the two species	temp ws temp*temp ws*ws temp*group
227	linear and quadratic effect of wind speed and temperature, and the linear effect of wind speed differs between the two species	temp ws temp*temp ws*ws ws*group
228	linear and quadratic effect of wind speed and temperature, and the linear effects of both temperature and wind speed differ between the two species	temp ws temp*temp ws*ws temp*group ws*group
229	linear and quadratic effect of temperature and wind speed, and interaction of the two, and the linear effect of temperature differs between the two species.	temp ws temp*ws temp*temp ws*ws temp*group
230	linear and quadratic effect of temperature and wind speed, and interaction of the two, and the linear effect of wind speed differs between the two species.	temp ws temp*ws temp*temp ws*ws ws*group
231	linear and quadratic effect of temperature and wind speed, and interaction of the two, and the linear effects of both temperature and wind speed differ between the two species.	temp ws temp*ws temp*temp ws*ws temp*group ws*group
232	linear and quadratic effect of temperature and wind speed, and interaction of the two differs between the two species.	temp ws temp*ws temp*temp ws*ws temp*group ws*group temp*ws*group

Appendix II Model selection results for all models.

Model # = number assigned by us to track individual models, Model = list of variables included in the model, k = number of estimated parameters, LL = log likelihood of the model, QAIC = AIC based on quasi likelihood,) = difference in QAIC of the model relative to the best model in the set, weight = Akaike weight associated with the model, cumwt = cumulative weight from the current model and all better models, relwt = weight of evidence in favor of the best model relative to the current model.

model#	model	k	ll	QAICc	delta	weight	cumwt	relwt
202	temp ws temp*hilow	11	-454.409	931.423	0.0000	0.13559	0.13559	1.00
210	temp ws temp*hilow temp*temp	12	-453.765	932.247	0.8235	0.08983	0.22542	1.51
220	temp ws temp*hilow ws*ws	12	-454.136	932.990	1.5670	0.06194	0.28736	2.19
205	temp ws temp*hilow temp*ws	12	-454.179	933.076	1.6526	0.05934	0.34670	2.28
204	temp ws temp*hilow ws*hilow	12	-454.366	933.448	2.0253	0.04925	0.39595	2.75
319	temp ws ws*ws ws*height	13	-453.322	933.483	2.0601	0.04841	0.44436	2.80
213	temp ws temp*hilow temp*ws temp*temp	13	-453.336	933.511	2.0879	0.04774	0.49210	2.84
103	temp ws	10	-456.780	934.064	2.6411	0.03620	0.52830	3.75
226	temp ws temp*temp ws*ws temp*hilow	13	-453.632	934.103	2.6801	0.03550	0.56380	3.82
212	temp ws temp*temp temp*hilow ws*hilow	13	-453.721	934.281	2.8583	0.03248	0.59627	4.18
223	temp ws temp*ws ws*ws temp*hilow	13	-453.991	934.820	3.3968	0.02481	0.62108	5.47
107	temp ws temp*temp	11	-456.143	934.892	3.4685	0.02394	0.64502	5.66
221	temp ws ws*ws ws*hilow temp*hilow	13	-454.093	935.025	3.6020	0.02239	0.66741	6.06
207	temp ws temp*ws temp*hilow ws*hilow	13	-454.136	935.111	3.6876	0.02145	0.68886	6.32
215	temp ws temp*ws temp*temp temp*hilow ws*	14	-453.293	935.555	4.1323	0.01718	0.70604	7.89
229	temp ws temp*ws temp*temp ws*ws temp*hil	14	-453.294	935.559	4.1354	0.01715	0.72319	7.91
322	temp ws temp*ws ws*height ws*ws	14	-453.297	935.564	4.1406	0.01710	0.74029	7.93
327	temp ws temp*temp ws*height ws*ws	14	-453.312	935.595	4.1716	0.01684	0.75713	8.05
106	temp ws ws*ws	11	-456.511	935.627	4.2042	0.01657	0.77370	8.18
109	temp ws temp*ws	11	-456.553	935.712	4.2889	0.01588	0.78958	8.54
208	temp ws temp*ws temp*hilow ws*hilow temp	14	-453.577	936.124	4.7005	0.01293	0.80251	10.49
228	temp ws temp*temp ws*ws temp*hilow ws*hi	14	-453.589	936.148	4.7246	0.01277	0.81528	10.62
110	temp ws temp*ws temp*temp	12	-455.719	936.155	4.7323	0.01272	0.82801	10.66
203	temp ws ws*hilow	11	-456.780	936.165	4.7419	0.01266	0.84067	10.71
216	temp ws temp*ws temp*temp temp*hilow ws*	15	-452.731	936.574	5.1508	0.01032	0.85099	13.14
303	temp ws ws*height	12	-455.952	936.621	5.1979	0.01008	0.86107	13.45
108	temp ws temp*temp ws*ws	12	-456.012	936.741	5.3182	0.00949	0.87057	14.28
224	temp ws temp*ws ws*ws ws*hilow temp*hilo	14	-453.947	936.865	5.4415	0.00893	0.87949	15.19
211	temp ws temp*temp ws*hilow	12	-456.142	937.002	5.5790	0.00833	0.88783	16.27
111	temp ws temp*ws ws*ws	12	-456.367	937.450	6.0273	0.00666	0.89448	20.36
321	temp ws ws*ws temp*height ws*height	15	-453.222	937.555	6.1318	0.00632	0.90080	21.45
231	temp ws temp*ws temp*temp ws*ws temp*hil	15	-453.251	937.613	6.1897	0.00614	0.90694	22.08
330	temp ws temp*ws ws*height temp*temp ws*w	15	-453.272	937.655	6.2315	0.00601	0.91296	22.55
311	temp ws temp*temp ws*height	13	-455.434	937.707	6.2836	0.00586	0.91882	23.15
219	temp ws ws*ws ws*hilow	12	-456.510	937.738	6.3146	0.00577	0.92458	23.51
206	temp ws temp*ws ws*hilow	12	-456.553	937.823	6.3994	0.00553	0.93011	24.52
225	temp ws temp*ws ws*ws ws*hilow temp*hilo	15	-453.388	937.886	6.4633	0.00535	0.93547	25.32
302	temp ws temp*height	12	-456.642	938.001	6.5778	0.00506	0.94052	26.81
209	temp temp*temp temp*hilow	11	-457.773	938.152	6.7288	0.00469	0.94521	28.92
306	temp ws temp*ws ws*height	13	-455.673	938.186	6.7624	0.00461	0.94982	29.41
112	temp ws temp*ws temp*temp ws*ws	13	-455.678	938.194	6.7709	0.00459	0.95442	29.53
214	temp ws temp*ws temp*temp ws*hilow	13	-455.718	938.276	6.8524	0.00441	0.95882	30.76
232	temp ws temp*ws temp*temp ws*ws temp*hil	16	-452.689	938.641	7.2179	0.00367	0.96250	36.93
310	temp ws temp*temp temp*height	13	-456.010	938.859	7.4355	0.00329	0.96579	41.17
227	temp ws temp*temp ws*ws ws*hilow	13	-456.011	938.861	7.4384	0.00329	0.96908	41.23
314	temp ws temp*ws temp*temp ws*height	14	-454.967	938.903	7.4802	0.00322	0.97230	42.10
305	temp ws temp*ws temp*height	13	-456.068	938.974	7.5511	0.00311	0.97541	43.62
313	temp ws temp*ws temp*temp temp*height	14	-455.063	939.095	7.6720	0.00293	0.97833	46.34
320	temp ws ws*ws temp*height	13	-456.338	939.515	8.0917	0.00237	0.98070	57.16
324	temp ws temp*ws temp*height ws*ws ws*hei	16	-453.140	939.541	8.1182	0.00234	0.98305	57.92
222	temp ws temp*ws ws*ws ws*hilow	13	-456.366	939.571	8.1475	0.00231	0.98535	58.78
328	temp ws temp*temp temp*height ws*height	16	-453.212	939.686	8.2630	0.00218	0.98753	62.27
230	temp ws temp*ws temp*temp ws*ws ws*hilow	14	-455.677	940.324	8.9008	0.00158	0.98911	85.66
304	temp ws temp*height ws*height	14	-455.850	940.669	9.2460	0.00133	0.99044	101.80
326	temp ws temp*temp temp*height ws*ws	14	-455.855	940.680	9.2566	0.00132	0.99177	102.34
104	temp temp*temp	10	-460.110	940.723	9.2996	0.00130	0.99307	104.56
323	temp ws temp*ws temp*height ws*ws	14	-455.886	940.743	9.3195	0.00128	0.99435	105.61

329	temp ws temp*ws temp*height temp*temp ws	15	-455.034	941.179	9.7554	0.00103	0.99538	131.33
331	temp ws temp*ws temp*height ws*height te	17	-453.086	941.595	10.1723	0.00084	0.99622	161.76
307	temp ws temp*ws temp*height ws*height	15	-455.319	941.749	10.3262	0.00078	0.99700	174.71
312	temp ws temp*temp temp*height ws*height	15	-455.332	941.775	10.3516	0.00077	0.99776	176.94
315	temp ws temp*ws temp*height ws*height te	16	-454.469	942.200	10.7769	0.00062	0.99838	218.87
201	temp temp*hilow	10	-460.940	942.384	10.9609	0.00057	0.99895	239.95
325	temp ws temp*ws temp*height ws*ws ws*hei	18	-452.880	943.355	11.9314	0.00035	0.99930	389.83
309	temp temp*temp temp*height	12	-460.002	944.721	13.2974	0.00018	0.99947	771.79
101	temp	9	-463.244	944.899	13.4760	0.00016	0.99963	843.87
332	temp ws temp*ws temp*height ws*height te	19	-452.807	945.390	13.9669	0.00013	0.99976	1000.00
308	temp ws temp*ws temp*height ws*height te	17	-455.031	945.485	14.0619	0.00012	0.99988	1000.00
316	temp ws temp*ws temp*height temp*temp ws	18	-454.121	945.836	14.4133	0.00010	0.99998	1000.00
301	temp temp*height	11	-463.134	948.874	17.4510	0.00002	1.00000	1000.00
102	ws	9	-478.916	976.242	44.8190	0.00000	1.00000	1000.00
100		8	-480.059	976.446	45.0233	0.00000	1.00000	1000.00
105	ws ws*ws	10	-478.655	977.814	46.3907	0.00000	1.00000	1000.00
217	ws ws*hilow	10	-478.915	978.333	46.9103	0.00000	1.00000	1000.00
318	ws ws*ws ws*height	12	-476.892	978.502	47.0784	0.00000	1.00000	1000.00
317	ws ws*height	11	-478.550	979.705	48.2822	0.00000	1.00000	1000.00
218	ws ws*ws ws*hilow	11	-478.655	979.915	48.4916	0.00000	1.00000	1000.00

Appendix III. Description of models compared in this study.

We compared a total of 12 models using AICc as described by Burnham and Anderson (2002) at each height (2m and 22m). All models included the species group design factor all 2-way interactions of species group (hilow) with environmental variables: distance to the mine (distmine), distance to the nearest water source (distwater), average minimum distance to forest edge and tree line (avedge), and the nearest edge (nearedge).

Model #	Description	Variables
0	Null model, no effect of species group or any environmental variables	
1	species groups have different average relative activity rates	hilow
2	linear effect of distance from mine is the same for both species groups	hilow distmine
3	linear effect of distance from mine is different for the two species groups	hilow distmine hilow*distmine
4	linear effect of distance from water is the same for both species groups	hilow distwater
5	linear effect of distance from water is different for the two species groups	hilow distwater hilow*distwater
6	linear effect of distance from forest or tree line edge is the same for both species groups	hilow avedge
7	linear effect of distance from forest or tree line edge is different for the two species groups	hilow avedge hilow*avedge
8	linear effect of distance from nearest edge is the same for both species groups	hilow nearedge
9	linear effect of distance from nearest edge is different for the two species groups	hilow nearedge hilow*nearedge

Appendix IV Model selection results for all models of two species groups.

Model # = number assigned by us to track individual models, Model = list of variables included in the model, k = number of estimated parameters, LL = log likelihood of the model, QAIC = AIC based on quasi likelihood,) = difference in QAIC of the model relative to the best model in the set, weight = Akaike weight associated with the model, cumwt = cumulative weight from the current model and all better models, relwt = weight of evidence in favor of the best model relative to the current model.

2 m

Model#	model	k	ll	AICC	delta	weight	cumwt	relwt
3	hilow distmine hilow*distmine	7	85.2774	101.1	0.00000	0.49530	0.49530	1.0000
0		4	94.3970	103.0	1.88784	0.19272	0.68802	2.5700
2	hilow distmine	6	90.0490	103.4	2.28196	0.15825	0.84628	3.1298
1	hilow	5	93.9359	104.9	3.75960	0.07559	0.92187	6.5522
4	hilow distwater	6	93.5398	106.9	5.77279	0.02763	0.94950	17.9286
5	hilow distwater hilow*distwater	7	92.9984	108.9	7.72100	0.01043	0.95993	47.4892
6	hilow avedge hilow*avedge	7	93.0072	108.9	7.72983	0.01038	0.97031	47.6992
7	hilow avedge hilow*avedge	7	93.0072	108.9	7.72983	0.01038	0.98069	47.6992
8	hilow nearedge hilow*nearedge	7	93.1531	109.0	7.87574	0.00965	0.99035	51.3092
9	hilow nearedge hilow*nearedge	7	93.1531	109.0	7.87574	0.00965	1.00000	51.3092

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22 m

Model#	model	k	ll	AICC	delta	weight	cumwt	relwt
0		4	98.7568	107.5	0.00000	0.42997	0.42997	1.0000
1	hilow	5	97.9865	109.1	1.59944	0.19325	0.62322	2.2249
2	hilow distmine	6	97.3829	110.9	3.45167	0.07654	0.69976	5.6172
8	hilow nearedge hilow*nearedge	7	95.4284	111.5	4.04391	0.05693	0.75669	7.5531
9	hilow nearedge hilow*nearedge	7	95.4284	111.5	4.04391	0.05693	0.81361	7.5531
4	hilow distwater	6	97.9832	111.5	4.05196	0.05670	0.87031	7.5835
3	hilow distmine hilow*distmine	7	95.4472	111.5	4.06278	0.05639	0.92670	7.6247
6	hilow avedge hilow*avedge	7	96.9305	113.0	5.54607	0.02686	0.95356	16.0071
7	hilow avedge hilow*avedge	7	96.9305	113.0	5.54607	0.02686	0.98042	16.0071
5	hilow distwater hilow*distwater	7	97.5631	113.6	6.17861	0.01958	1.00000	21.9618

Appendix V Model selection results for all models of *Myotis*.

Model # = number assigned by us to track individual models, Model = list of variables included in the model, k = number of estimated parameters, LL = log likelihood of the model, QAIC = AIC based on quasi likelihood,) = difference in QAIC of the model relative to the best model in the set, weight = Akaike weight associated with the model, cumwt = cumulative weight from the current model and all better models, relwt = weight of evidence in favor of the best model relative to the current model.

2 m

Model #	model	k	ll	AICC	delta	weight	cumwt	relwt
2	distmine	3	41.6432	48.4	0.00000	0.84203	0.84203	1.0000
0		2	49.3541	53.7	5.29805	0.05955	0.90158	14.1402
4	distwater	3	47.4260	54.2	5.78283	0.04673	0.94831	18.0188
6	avedge	3	48.1267	54.9	6.48357	0.03292	0.98123	25.5793
8	nearedge	3	49.2500	56.1	7.60687	0.01877	1.00000	44.8550

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22 m

Model #	model	k	ll	AICC	delta	weight	cumwt	relwt
0		2	45.9755	50.4	0.00000	0.36541	0.36541	1.00000
4	distwater	3	44.8176	51.7	1.30236	0.19054	0.55595	1.91780
2	distmine	3	44.9787	51.9	1.46353	0.17579	0.73174	2.07874
6	avedge	3	45.2455	52.1	1.73026	0.15384	0.88558	2.37531
8	nearedge	3	45.8375	52.7	2.32225	0.11442	1.00000	3.19353