New York State Energy Research and Development Authority

Multi-Year Acoustic Monitoring of Bats at the Maple Ridge Wind Project

Final Report

December 2011

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Multi-Year Acoustic Monitoring of Bats at the Maple Ridge Wind Project

Final Report

Prepared for the

New York State Energy Research and Development Authority

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SUMMARY

The post-construction wildlife monitoring program at the Maple Ridge Wind project is one of the most extensive investigations on the impact of wind development on wildlife at any site in the world. As part of this investigation, North East Ecological Services (NEES) was contracted to design and conduct a multi-year acoustic monitoring program to understand how bats use the landscape and what factors put them at greatest risk of collision with the turbines. Using a vertical sampling array and multiple sampling platforms across the project site, NEES explored the temporal (nightly and seasonal) and spatial (horizontal and vertical) distribution of bat activity across the project site. NEES analyzed the impact of meteorological variables on bat activity that may help inform predictive models used for adaptive management in order to reduce the impact of wind development on migratory bats.

Acoustic monitoring data were collected at four meteorological towers across the project site using the Anabat™ ultrasonic monitoring system. Each 'met tower' was outfitted with monitors at ground level (10 m), supracanopy height (30 m), and turbine height (50 m or 80 m) for two complete active seasons (2007 and 2008). At total of 19,991 bat calls were recorded at the project site over the two year sampling period; there was no significant difference in the pattern of bat activity between the two years, although mean bat activity declined 33% in 2008 relative to 2007. Most of this decline occurred at the ground-level detectors and may reflect the impact of White-Nose Syndrome on summer bat activity in the project area. Seasonal analysis of the data suggests that bat activity was highest during the summer months with lower levels of activity during the spring and fall migratory seasons. In both years, the peak activity at turbine height occurred in the early fall (late August - early September). There was a significant difference in bat activity between the sampling towers, with the Flat Rock tower accounting for 52% of the total bat activity. Other than overall activity, there was no evidence that the temporal pattern or species composition of the bat activity differed between the sampling towers. Therefore, multiple towers may provide different indices of bat activity but generally provided that same pattern of bat activity. As shown in many other studies, most of the bat activity (59%) was near the ground, with less activity at the supracanopy (25%) and turbine (16%) height. Hoary bats were the only species that showed a significant altitudinal pattern, with significantly more hoary bats heard at elevated detectors than near the ground.

Analysis of the nightly variation in bat activity showed that very little bat activity was detected prior to 20:00, even in the fall when sunset was relatively close to this time. Using absolute time measurements, daily bat activity generally peaked at 21:30 with virtually no bat activity prior to 20:00 or after 05:30. Analyzing the time relative to sunset revealed that there was very little bat activity prior to sunset and all of this pre-sunset activity occurred during the spring migratory season. Interestingly, most of this activity occurred at the ground-level monitors more than 30 minutes before sunset. Across the nightly sampling period, 61% of the total bat activity occurred within the first four hours after sunset, with bat activity peaking earlier at the higher detector heights. Red bats and hoary bats showed a highest level of activity within the first two hours of sunset compared to the other species. Most of the bat species showed temporal activity patterns that were independent of sampling height; the exception was the silver-haired/big brown

bat species group that was active significantly later than the other migratory bats at the elevated detectors.

Statistical analysis of the meteorological data showed that many of the variables had no influence on bat activity, including barometric pressure, wind direction, cloud cover, cloud ceiling height, or moon cycle. Multiple variable analysis using regression trees revealed that the most predictive variable was ambient temperature, with nightly bat activity tripling when mean nightly air temperature was above 13.4°C. For all bats, the highest bat activity occurred when air temperature was above 17.6°C and wind speed was below 2.5 m/s (5.5 mph). Just looking at the turbine height monitors, air temperature was the strongest predictor of bat activity, with low wind speed and high relative humidity increasing total bat activity. Looking only at hoary bats (the species killed at the highest level at wind development sites), regression tree analysis revealed that season is the strongest predictor of bat activity, with the fall sampling period having four times the hoary bat activity as other times of the year. Within the fall sampling period, hoary bat activity tripled on warm and humid nights. It is possible that peak fall migratory activity may precede the high humidity conditions that occur when cold fronts move across the landscape. Because cold fronts in the northern hemisphere generally produce winds from the north or northwest, passage of a cold front may provide favorable wind conditions for the fall migration. The reliance on predictable wind patterns, such as the passage of a cold front, would be an effective way of orienting migratory behavior and would eliminate the need for a precise compass sense or other navigational aid; this may be particularly important for bats, which rely on short-range acoustics to navigate under non-migratory conditions. In general, *Myotis* bat activity was significantly less influenced by meteorological variables compared to the migratory bats but still showed a strong seasonal (highest in summer) effect and a preference for low wind conditions.

In addition to the long-term monitoring of bat activity using stationary platforms, NEES developed and deployed a mobile aerial sampling platform to test at the Maple Ridge project site. During the peak fall migratory period in 2008, NEES deployed a tethered dirigible with an Anabat monitor on the project site to determine whether aerial platforms were a viable alternative to stationary platforms when met towers were not available. The dirigible was raised to 250 feet altitude with the detector positioned due north for an entire evening. Despite an average wind speed of 9.8 m/s (22.0 mph), the dirigible recorded eight calls from hoary and red bats, for a detection rate that was four times higher than the overall detection level of bats at the turbine height detectors positioned on the met towers during the same sampling interval.

In many respects, the data collected as part of this NYSERDA research effort are consistent with data collected at many other wind project sites. These results highlight some of the temporal, spatial, and environmental components of bat activity that may play an important role in predicting the impact of wind development on bat populations at future wind development sites. Still, the most significant and cautionary findings are the strong interaction effects observed between these variables. These strong interactions, particularly the impact of species and season on bat activity, suggest that separate analyses of summer foraging (primarily of *Myotis spp*. and big brown bats (*Lnoct-Efusc*) and migratory behavior (primarily of hoary bats and red bats) may provide a clearer picture of a projects' potential impact.

Although successful monitoring programs such as this provide information that has direct relevance and use, often too much emphasis goes into data collection and not enough on data management and use. The 'grand challenge', as identified by Kunz et al. (2007), is to develop creative solutions that produce a win-win scenario where the wind industry realizes predictable and responsible growth while providing data that allow scientists to minimize the impact of this development on wildlife. The NYDEC Guidelines for Conducting Bird and Bat Studies at Commercial Wind Energy Projects (NYDEC, 2009) is a tool to realize this goal. These data suggest that the NYDEC protocol is well designed and capable of characterizing bat activity across a project site. The focus on a single year of pre-construction acoustic monitoring should adequately characterize the seasonal activity at the project site; additional years of pre-construction monitoring are unlikely to provide qualitatively different results. The NYDEC protocol also focuses on ensuring appropriate vertical sampling of a potential wind development site using met towers. Data collected at the Maple Ridge project site confirm that high altitude sampling is the most appropriate method for documenting migratory bat activity. Although the NYDEC protocol does not mention the need for multiple sampling platforms, data collected at Maple Ridge suggest that multiple sampling platforms may produce different measures of bat activity but that each platform produced similar overall patterns. This report offers only three potential modifications to the NYDEC protocol. First, data collected in this study suggest relying on relative sunset time produces unequal sampling effort across the year (as total sampling time varies seasonally) and may miss some of the pre-sunset migratory activity seen in the spring. Although this is unlikely to change the overall measures of bat activity, absolute time measures may be statistically more appropriate and capture more bat activity than sampling protocols relying on relative sunset time. Second, data from the current study suggest that there are strong interactions between sampling variables (particularly between sampling height, season, and species) that may be lost by relying on a single metric of overall bat activity. NEES suggests that bat activity indices be generated for each sampling season (spring, summer, and fall) and for each sampling height. For species with adequate sample sizes, it may also be useful to document both overall activity levels and activity levels at each height or season.

Lastly, the NYDEC does not outline options available to wind developers when a met tower is not available for attaching acoustic monitors. At several project sites with which NEES has been involved, state regulators generally focus on more extensive ground-level monitoring to compensate for the lack of vertical sampling. Data collected for this study suggests that additional ground monitoring will produce valuable data, but it will not provide information on migratory bat activity. Given that sampling height was the largest source of variation in the current study, these data are unlikely to be comparable to met tower-based projects due to the fact that ground detectors have higher levels of overall bat activity and are generally different from elevated detectors in both their seasonal variation and species composition. Tethered dirigibles may be a viable alternative that supplements ground monitoring stations with turbine-level monitoring during peak fall migration.

1.0 PROJECT OBJECTIVES

Research conducted at wind development sites across the United States and Europe suggest that most bat mortality occurs during migration. Consequently, an understanding of the migratory bat activity at the Maple Ridge Wind Project site during the first several years of operation is critical in understanding the potential impact of this project on bats. The objectives of this project were to collect data to help understand the spatial and temporal patterns of bat activity across the project site. These data, collection in conjunction with environmental data, will help determine the key environmental conditions that are predictive of bat activity; such information may help inform decisions relating to project mitigation or impact avoidance. These studies have been completed for the summer breeding season and the fall migratory season using a protocol that is consistent with the recommendations of the New York Department of Environmental Conservation (NYDEC) and the National Research Council (NRC, 2007) guidelines.

2.0 DATA COLLECTION

2.1 Equipment Setup and Data Collection

Data were collected using Anabat™ SD-1 (Titley Electronics, Australia) ultrasonic detection systems placed at multiple heights along four meteorological towers installed across the project site (Figure 2). Three of the meteorological towers (Flat Rock, Gardner, and Cobb) were 80m lattice towers, while the fourth tower was a 50m monopole tower (Porter). At each of the towers, a microphone was placed at 10m altitude ('LOW') and at 30m altitude ('MID'). The top microphone ('HIGH') was placed at approximately 79m on the 80m towers and 49m on the 50m tower. All microphones were installed with the receptive field facing north (0° azimuth) during the fall migratory period and facing south (180° azimuth) during the spring migratory period. Microphones were mounted to each tower using a pulley system that allowed equipment retrieval in the event of failure or other maintenance. The microphones were housed in a weather-tight PVC housing and oriented toward the ground to prevent moisture from collecting on the transducer. A 10 cm^2 square Lexan sheet was mounted below the microphone at 45° from horizontal to deflect sound up toward the microphone. Microphones were attached to the detectors using customized cables (EME Systems, Berkeley, California) based on a Canare Starquad™ video cable with an additional preamplifier soldered into the terminal end of the cable to increase signal strength. The Anabat™ SD-1 interface module stores bat echolocation signals on removable CF-flash cards. The detectors were placed in a NEMA-4 weatherproof enclosure mounted to the base of the platform and powered by a 30W photovoltaic charging system.

The Anabat monitoring systems were programmed to monitor for ultrasonic sound from 18:00 – 08:00 each night throughout the sampling period (10 May – 15 December, 2007 and 01 April - 30 November, 2008). Data storage cards were retrieved by NJ Audubon and MRWP personnel at approximately biweekly intervals. At each visit to the tower, the data cards were removed from each recording system and replaced with new cards. All card removals and replacements were documented on field sheets provided and stored in each tower enclosure. Data storage cards were mailed to NEES in protective envelopes for analysis.

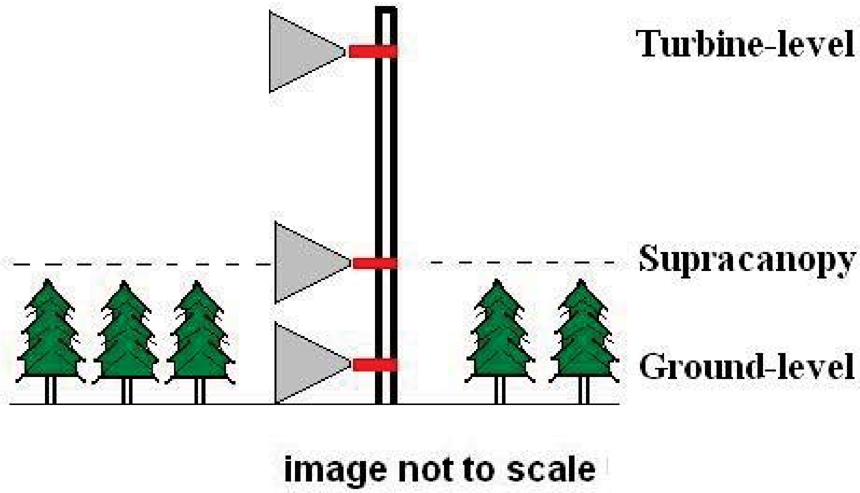


Figure 1. Photograph of a Typical Meteorological Tower Sampling Platform

2.2 Equipment Calibration

All microphones and cables were calibrated (before installation and after de-construction) in a test facility using a Binary Acoustics AT-100 multifrequency tonal emitter (Binary Acoustics Technology , Las Vegas, Nevada) to confirm minimum performance standards for six different ultrasonic frequencies (20kHz, 30kHz, 40kHz, 50kHz, 60kHz, and 70kHz). In addition, a minimum cone of receptivity (15° off-center) was verified by rotating the microphone horizontally on a platform using the AT-100 as a sound source.

2.3 Data Storage

Data were retrieved from the data storage cards using the CFReader ™ (Titley Electronics, Australia) software. Data files were stored in electronic folders specific for each tower and microphone. All data files recorded in a single nightly sampling period (1800 - 0600) were stored in a night-specific folder designated by the date in which sampling began. Preliminary data filtering was done using Analook ™ (Titley Electronics, Australia) software.

3.0 DATA ANALYSIS AND STATISTICS

3.1 Data Assumptions and Presentation Format

The following data were collected in order to characterize the bat activity that occurs at the Maple Ridge Wind Project site. Several assumptions were made in order to characterize this activity:

a) bat activity recorded at the monitoring tower adequately represents bat activity across the Project site.
b) the microphones are properly oriented to record echolocation calls of bats as they fly across the Project site

c) there is relatively little bat activity during the daytime (0600 – 1800)
d) the sampling period (30 Mar through 30 Nov) accurately represents the entire active season of bats at the Project site
e) the echolocation calls recorded on unique data files are independent and do not represent the same individual over multiple sampling periods
f) echolocation calls within the same data file can be treated as a set of calls from a single individual

Assumption a) is based on the technological and methodological constraints that exist at a wind development project. Prior to the concern about turbine-related bat mortality, there were only a few studies that attempted to acoustically document bat migratory activity (for example, Zinn and Baker, 1979; Barclay, 1984). Even fewer studies attempted to document bat activity at altitudes above the tree canopy (for example, Davis et al., 1962; McCracken, 1996). This lack of emphasis was due to the difficulty of recording ultrasonic sound over large periods of time (limitations of recording equipment), wide areas of space (high signal attenuation of ultrasonic wavelengths), or at high altitude. Assumption b) remains a relatively open question and state biologists deal with the issue of migratory orientation in a variety of ways. In order to make these data most comparable to other projects in New York, all the microphones were oriented facing north during the fall migratory season and south during the spring migratory season, in accordance to the New York Department of Environmental Conservation monitoring protocol (NYDEC, 2009). Assumption c) has been validated by numerous field studies and therefore is strongly supported by existing data. Assumption d) is consistent with our understanding of temperate bat biology and has been validated by a variety of wind development sites across the eastern United States. Assumptions e) and f) relate to how bat calls are recorded and represented. Although there is a wide range of opinion on how to interpret echolocation calls, there is a general agreement that researchers should not use echolocation call files as a measure of species abundance unless those calls are independent. This requires that data are collected and analyzed to ensure the spatial- and temporal-independence of each recording. Spatial independence is created by placing microphones in non-overlapping sampling environments. The microphone configuration used in the present study intentionally placed microphones in the same sampling environment to test the impact of microphone angle on bat activity indices; therefore, there was no spatial independence in the sampling environment. Temporal independence can be created by making assumptions about the time individual bats will remain within the sampling space. Because we do not have adequate research on migratory activity, we cannot make well-grounded assumptions about temporal independence of individual calls. For example, two bat calls recorded at the HIGH microphone within ten seconds may represent a single bat flying near the microphone. Still, two calls recorded 60 minutes apart are unlikely to represent the same bat. To avoid this potential non-independence, this report will focus on total bat activity, not species abundance or species evenness (relative abundance of each species).

Table 1. Summary of terms and definitions used to describe bat activity

bat activity	total number of echolocation calls recorded per monitor ('total bat calls')
high risk species	bats species known to collide with wind turbines at rates higher than predicted based on their abundance during capture (e.g. mist netting) sampling
calls/detector-night (calls/dn)	standardized measure of bat activity (controlling for variation in total sampling effort at each site)
peak 7-day activity	estimate of peak sustained migratory activity
peak fall migration	bat activity from 01 August through 30 September
peak spring migration	bat activity from 01 April through 31 May
peak summer activity	bat activity from 01 June through 31 July
fall migration	bat activity from 16 August through 15 November
spring migration	bat activity from 15 March through 14 June
summer activity	bat activity from 15 June through 15 August

3.2 Data Analysis Protocol

Data were analyzed using the Analook™ 4.9j graphics software. Bat echolocation recordings were separated from non-bat sounds based on differences in time-frequency representation of the data (Table 2). Data files were preserved if they contained a "bat pass" sequence, defined as at least two distinct pulses within the same file. All files that lacked at least two distinct bat pulses were marked for deletion and not included in subsequent analyses. All data files were analyzed using a semi-quantitative approach that compared diagnostic call features (maximum call frequency, minimum call frequency, call duration, slope, and inter-pulse interval) with a dichotomous key developed for bats of the northeast. Species identification was conservative to minimize identification error and maximize total number of calls included in the analysis. Because the focus of the project was to determine overall bat activity, data files were only identified to species when those species had distinct acoustic signatures. When multiple species had overlapping acoustic signatures, a phonic group was created that contained all such species. Specifically, high variation in calls within the genus *Myotis* precludes reliable species identification (Murray et al., 2001; Jones et al. 2004). We grouped silver-haired bats (*Lasionycteris noctivagans*) and big brown bats (*Eptesicus fuscus*) into a single group (Lnoct-Efus) to reduce errors in identification of these two species. For those calls that were not of a high enough quality to extract diagnostic features, an "Unknown Bat" category was used to document total bat activity.

The use of phonic groups and a subjective classification system have the advantage of maintaining more files for analysis because the researcher can retain many data files that would be removed by species-specific filters. Subjective classification systems such as this have been proven highly effective and reliable when conducted by experienced researchers (Limpens, 2004; Parsons and Szewczak, 2009). When all data files had been removed or analyzed to species group, measures of bat activity were generated for each microphone as total bat calls per monitoring night (calls/detector-night). These measures represent overall bat activity at each sampling point and do not necessarily measure total number of bats.

Table 2. Descriptive breakdown of acoustic file source origins

Category	General Description of Time-Frequency Analysis of Data	Probable Source(s)
Wind Noise	Random pixilation with little to no pattern	wind
Mechanical	Long calls (> 100 ms) with high constant-frequency (CF) component and drifting characteristic frequency (Fc)	cable resonance EM interference
Biological (non-bat)	Frequency-modulated (FM) call structure with ascending pitch or with characteristic frequency in audible range	insects birds, flying squirrels
Bat Activity	FM or CF dominated data file with species-specific call durations, pitch changes, or other attributes	bats

3.3 Statistical Analysis

The acoustic data were analyzed on multiple spatial and temporal scales to look for large-scale patterns in bat activity across the project site. In addition, bat activity data were analyzed in reference to environmental conditions at the project site based on meteorological data collected by the National Weather Service at the Watertown Municipal Airport approximately 30 miles northwest of the project site. Initial data analysis involved plotting bat activity with the meteorological variables by using scatter-plots (for continuous variables) and box-plots (for discrete variables). Prior to conducting multivariate analyses, we also generated a correlation matrix for all predictor variables to look for indications of severe multicollinearity.

To explore the relative ability of each predictor variable to explain the observed variation in bat activity, we used the 'random forest' algorithm in the open source R statistical programming language (R Development Core Team, 2010; Liaw and Wiener 2002). We used the random forest algorithm due to its ability to handle complex non-linearities and interactions among predictor variables, resistance to over-fitting, and robustness to non-normality, outliers, and temporal and spatial autocorrelation among observations (Breiman, 2001; Evans and Cushman, 2009; Cutler et al., 2007). In the random forest algorithm, 1,500 CART (classification and regression tree) models were constructed via an iterative bootstrap (sampling with replacement, 64% of data per bootstrap replicate) with each successive split based on a rule derived from a random subsample of 1/3 of the available predictor variables. The relative “importance” of each predictor variable was assessed as the average (mean) decrease in classification accuracy (or mean squared error for regression trees) for the “out-of-bag” portion of the data (observations not used to build the CART model) when that variable was factored out of the analysis (Liaw and Wiener 2002). Using only the predictor variables deemed “important” in the random forest analysis, additional CART analyses were conducted to determine the partitioning rules that would provide the highest level of correct classification for bat activity: e.g. what wind speed best separates nights with low bat activity from nights with high activity?; Therneau and Atkinson 2010). In addition, general linear models and ANOVAs were run on the same driver variables to generate more traditional multivariate models and significance tests.

4.0 SEASONAL AND TEMPORAL RESULTS

4.1 Seasonal Variation in Bat Activity

4.1.1 Seasonal Variation in Bat Activity, 2007

Bat activity across the MRWP site was highly seasonal in 2007, with the highest sustained activity during the summer months and peak activity periods into the fall migratory season (Figure 2). Across all microphones, peak bat activity was documented on 09 September (primarily from bat activity at the LOW microphone at the Flat Rock Tower site), with peak sustained bat activity occurring during the seven-day period beginning 23 July. Peak bat activity at the HIGH microphones occurred on 30 August, with peak sustained bat activity occurring during the seven-day period beginning 22 July.

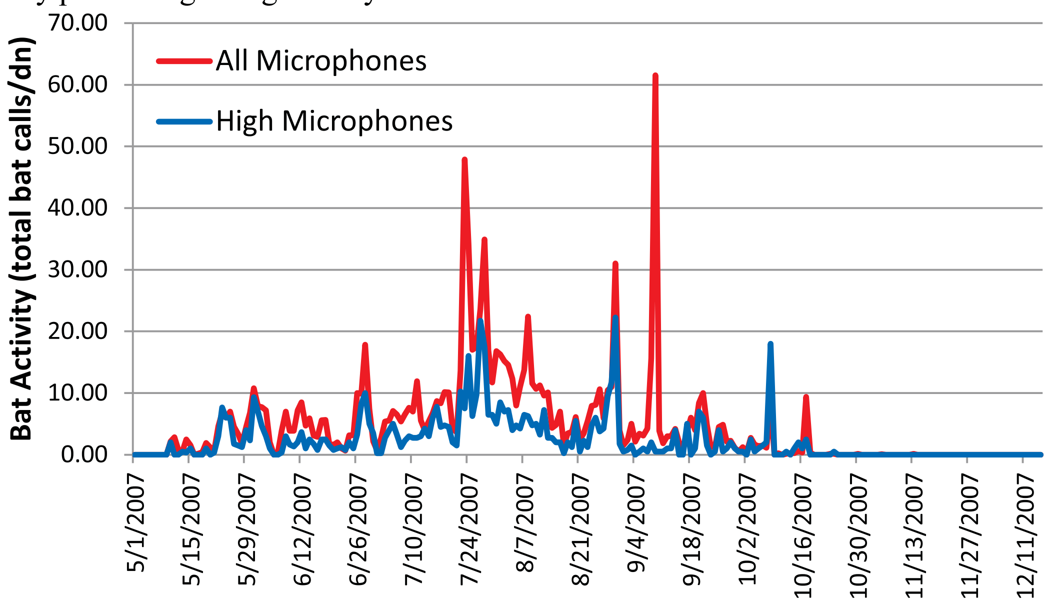


Figure 2. Seasonal Variation in Bat Activity Across the MRWP Site, 2007

4.1.2 Seasonal Variation in Bat Activity, 2008

Bat activity across the MRWP site was also highly seasonal in 2008, with the highest sustained activity during the summer months and peak activity periods into the fall migratory season (Figure 3). Across all microphones, peak bat activity was documented on 06 August (primarily from bat activity at the LOW microphone at the Cobb Road Tower site), with peak sustained bat activity occurring during the seven-day period beginning 31 July. Peak bat activity at the HIGH microphones occurred on 06 September, with peak sustained bat activity occurring during the seven-day period beginning 19 July.

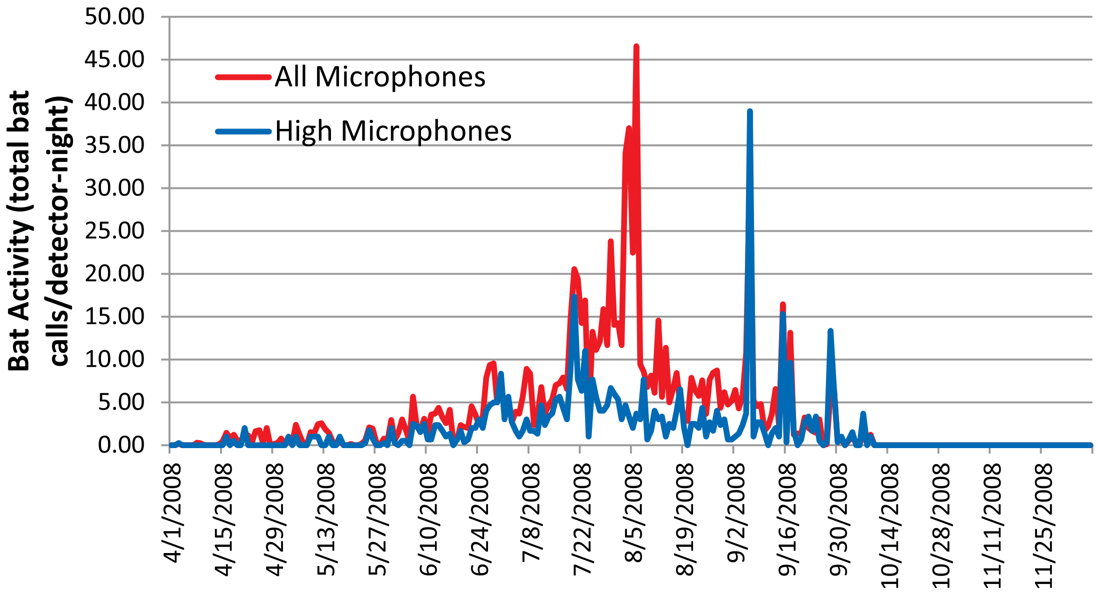


Figure 3. Seasonal Distribution in Bat Activity Across the MRWP Site, 2008

4.1.3 Comparison of Seasonal Variation in Bat Activity

Bat activity showed a consistent temporal pattern between the two sampling years with no significant inter-annual variation in overall activity ($t=89.2$, $p> 0.20$). Specifically, each year had a single high-activity peak in late July, with peak activity at the turbine height occurring in early fall. In both cases, the 2008 peak activity periods were roughly one-week later than the peak periods in 2007. The lack of bat activity during the beginning of both sampling years suggest that the entire active period of bats was monitored using an April through November sampling period.

Mean nightly bat activity declined 33.2% from 2007 to 2008 (from 5.72 bats/dn to 3.82 bats/dn). Activity at the HIGH microphones declined 35.9% from 2007 to 2008. This difference in bat activity appears to be an artifact of the variation in the sampling period across the two years; monitoring began on 10 May, 2007 and 30 March, 2008. To remove the effect of this differential starting period, we analyzed bat activity during the peak activity period (July - September). This analysis showed that bat activity declined 6.7% from 2007 to 2008 (9.11 bats/dn to 8.50 bats/dn). Bat activity at the HIGH microphones declined 5.1% during this same time period. This decline appears to be the result of reduced early summer bat activity at the project site in 2008, particularly at the LOW microphones. This decline was most dramatic at the Flat Rock Tower site.

4.2 Temporal Variation in Bat Activity

Bat activity was detected across most of the 14-hour sampling period during the two year study. In general, there was very little bat activity prior to 20:00 regardless of the time of year. The vast majority (97%) of this early activity (pre-20:00) occurred during the fall migratory period (September through November) when sunset was relatively early. The remaining 3% occurred during the spring migratory period prior to sunset.

4.2.1 Temporal Variation in Bat Activity, 2007

Bat activity was distributed throughout most of the daily sampling period, peaking at approximately 21:30 across all seasons (Figure 4). There was virtually no bat activity during the first hour and last hour of sampling and the first two hours and final two hours of sampling represented only 1.10% and 0.05% of the total bat activity, respectively. Activity at each microphone height had a similar temporal distribution of bat activity.

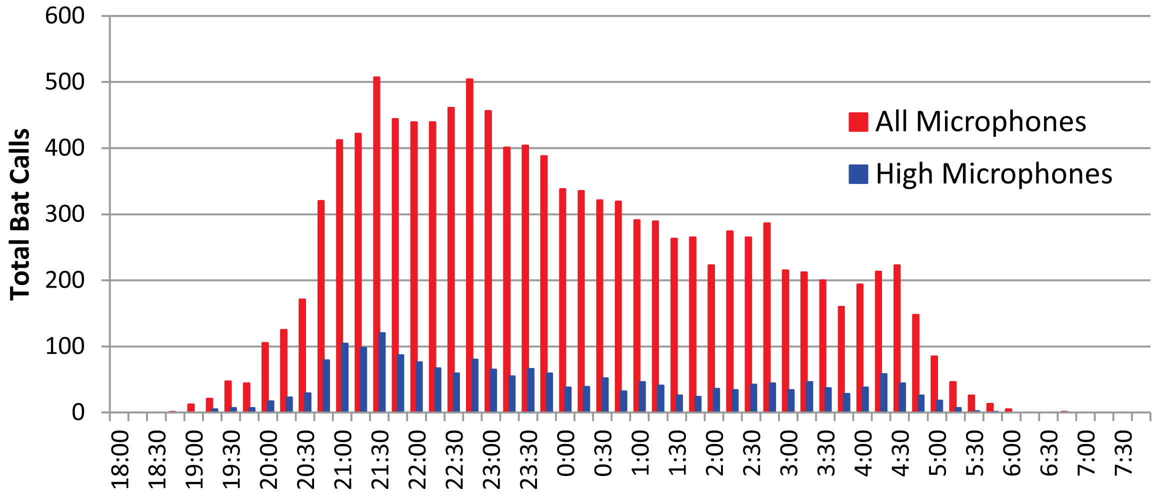


Figure 4. Temporal Variation in Bat Activity Across the MRWP Site, 2007

4.2.2 Temporal Variation in Bat Activity, 2008

Bat activity was distributed throughout most of the daily sampling period, peaking at approximately 21:15 across all seasons (Figure 5). There was virtually no bat activity during the first hour and last hour of sampling and the first two hours and final two hours of sampling represented only 1.43% and 0.01% of the total bat activity, respectively. Similar to the 2007 data, activity at each microphone height had a similar temporal distribution of bat activity.

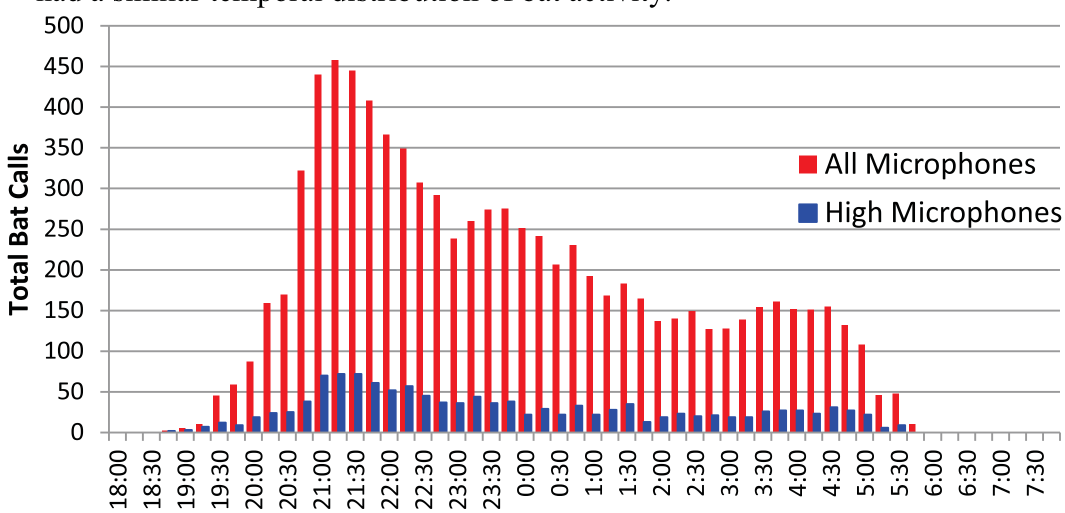


Figure 5. Temporal Variation in Bat Activity Across the MRWP Site, 2008

4.2.3 Temporal Variation in Bat Activity Relative to Sunset

There was very little pre-sunset bat activity documented during the two year study. All the pre-sunset bat activity (n=9 in 2007 and n=1 in 2008) occurred during the spring migration period and 80% of the calls were detected at the ground (LOW) microphones. Of this pre-sunset bat activity, 70% occurred more than 30 minutes before sunset. Across the entire active period for both sampling years, 34% of the bat activity occurred within the first two hours of sunset and 61% occurred within the first four hours of sunset (Figure 6). There was a significant difference in the distribution of bat calls, relative to sunset, across the different sampling heights ($X^2_{df=3}$=86.5, $p< 0.01$), with significantly more early bat activity (within the first two hours of sunset) at the HIGH and MID microphones relative to the LOW microphone. There also appears to be a significant interaction between sampling height and species, with the silver-haired/big brown bat species group (*Lnoct-Efusc*) active significantly later than other species at the elevated microphones ($F_{11,198}$ =5.81, $p<0.01$).

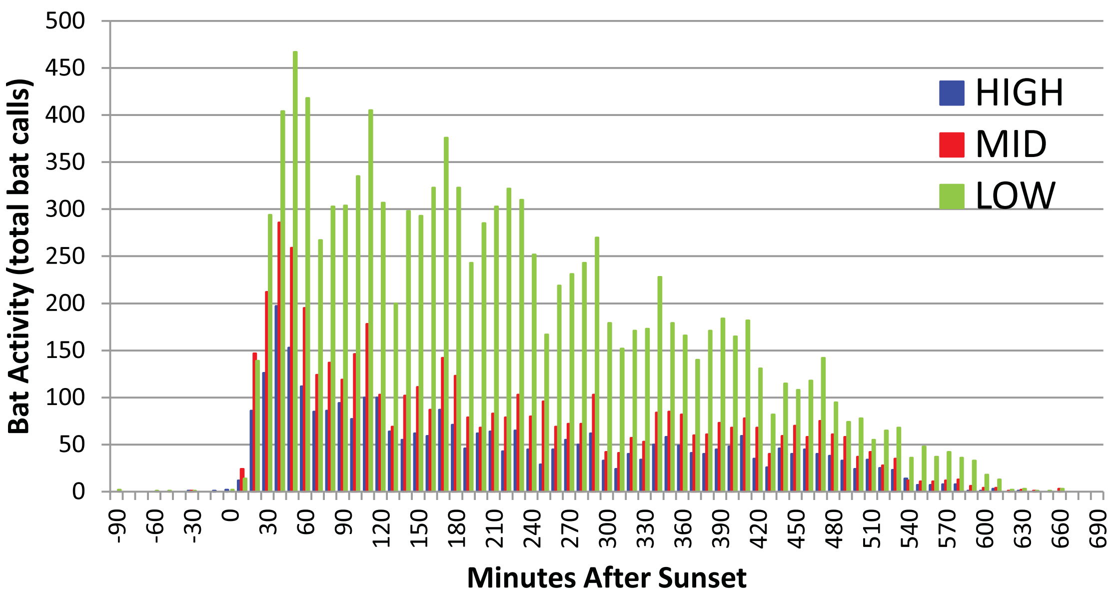


Figure 6. Temporal Variation in Bat Activity Relative to Sunset (both years combined)

The remaining species groups showed temporal activity patterns that were independent of sampling height. Across the entire active season, activity in the *Myotis spp.* showed a higher level of activity in the first four hours after sunset compared to the remainder of the evening; after this initial activity, there was a linear decrease in *Myotis spp.* activity over time relative to sunset. Red bats (*L. borealis*) and hoary bats (*L. cinereus*) both showed a relatively high level of activity immediately after sunset, with 39% and 37% of all activity detected within the first two hours after sunset (compared to only 27% for *Myotis spp.*). After this initial high level of activity, both migratory species showed stable levels of activity throughout the remainder of the evening (Figure 7). There was a significant difference in the distribution of bat activity between these species, with *Myotis spp.* having relatively less bat activity early in the evening compared to the migratory species ($X^2_{df=3}$=84.1, p< 0.01). This difference in activity disappeared within the first four hours after sunset ($X^2_{df=3}$=6.1, p> 0.05), as all three species groups had roughly 60% of their total activity within these first four hours.

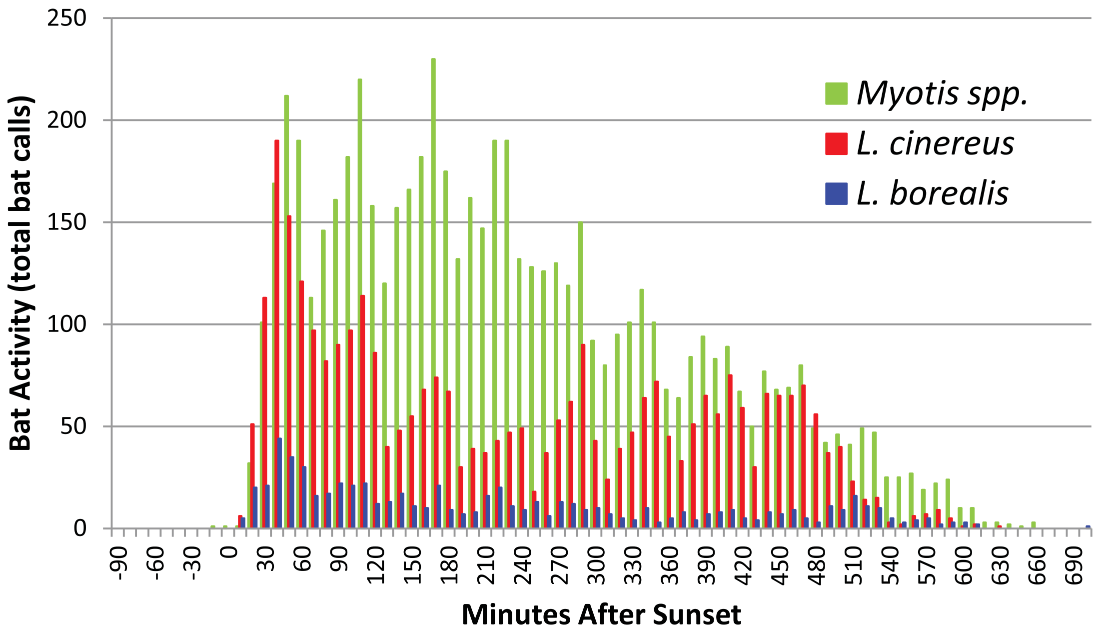


Figure 7. Temporal Variation in Bat Activity Relative to Sunset (both years combined)

4.3 Spatial Variation in Bat Activity

4.3.1 Differences in Bat Activity Between Towers

There was a significant difference in bat activity between the sampling towers ($F_{14,201}$ =6.47, p<0.01), with the Flat Rock tower accounting for 52% of the total bat activity (Figure 8). Despite this difference, there was no evidence that the distribution of bat activity across species or sampling heights differed between the towers.

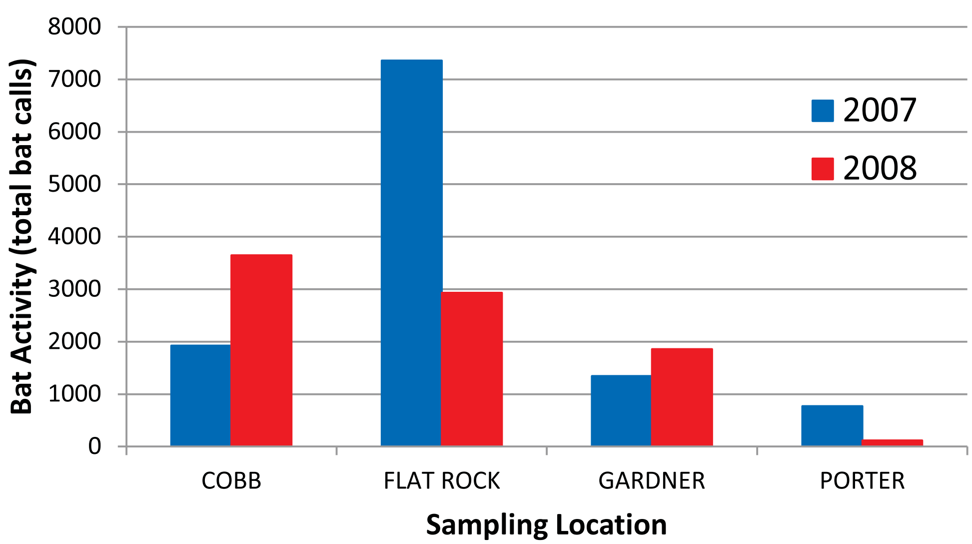


Figure 8. Spatial Variation in Bat Activity Relative to Sampling Location

4.3.2 Differences in Bat Activity Between Sampling Height

There was a significant difference in bat activity between the sampling heights ($F_{11,60}$ =6.88, p<0.01), with the 59% of the bat activity being detected at the ground-level (LOW) microphones, compared to 25% at the 30m (MID) and 16% at the turbine height (HIGH) microphones (Figure 9). The only significant interaction effect we discovered was the positive influence of sampling height on hoary bat activity, suggesting that hoary bats were more frequently detected at elevated microphones that predicted (t=154.5, p< 0.01). Despite this difference, there was no evidence that the distribution of bat activity across species or sampling heights differed between the towers.

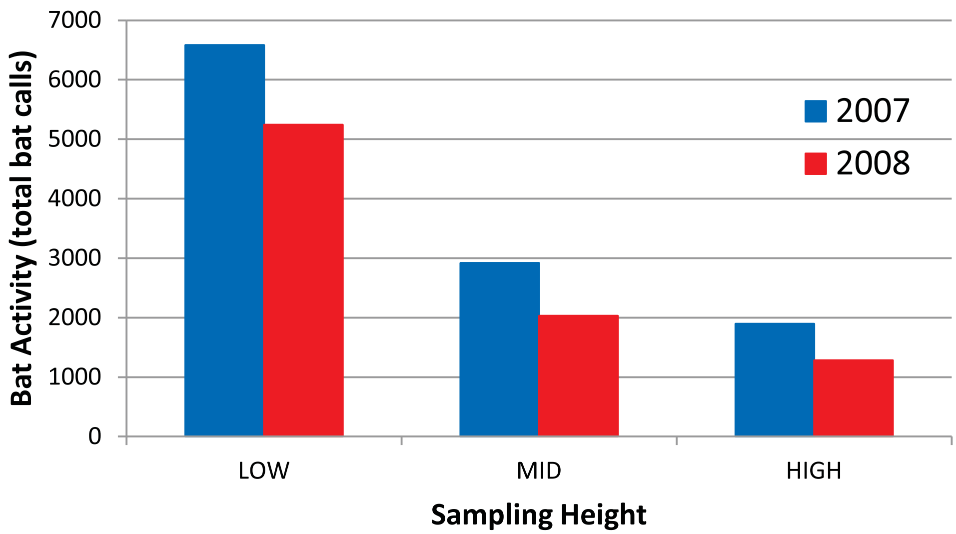


Figure 9. Spatial Variation in Bat Activity Relative to Sampling Height (all towers combined)

5.0 SITE-SPECIFIC DATA - FLAT ROCK

5.1 Sampling Effort at the Flat Rock Site

Bat activity was monitored at the Flat Rock Road Tower site from 10 May through 15 December, 2007 and again from 30 March through 30 November 2008. The total sampling period was 220 days (3,080 hours per detector) in 2007 and 246 days (3,444 hours per detector) in 2008. Due to a variety of conditions, the actual sampling effort of each microphone was less than this maximal potential sampling effort (Table 3).

Table 3. Acoustic Sampling Effort at the Flat Rock Tower Site

	Microphone	Total Days Monitoring	Percent of Total Monitoring	Reasons for Data Loss (days of loss)
2007	LOW	218	99.1%	card overload (2)
	MID	220	100.0%	
	HIGH	187	85.0%	card failure (16) card overload (17)
	AVERAGE	**208.3**	**94.7%**	
2008	LOW	246	100.0%	
	MID	246	100.0%	
	HIGH	198	80.5%	card overload (33) card failure (15)
	AVERAGE	**230.0**	**93.5%**	
OVERALL	**AVERAGE**	**219.2**	**94.1%**	

5.2 Summary of Data Collection at the Flat Rock Site

A total of 87,663 files was recorded by the acoustic monitoring equipment. After analysis, 10,241 files (11.7%) were determined to be of bat origin. Combining data from all microphones, bat activity was documented on 143 of the sampling days in 2007 (65.0%) and 161 of the sampling days in 2008 (65.4%); across the two years, 52.8% of the non-activity days occurred after October 31. A depiction of overall bat activity at the Flat Rock Tower site is shown in Figure 10. Each pie graph is scaled to represent total relative activity (with actual bat calls identified by the numbers next to each graph).

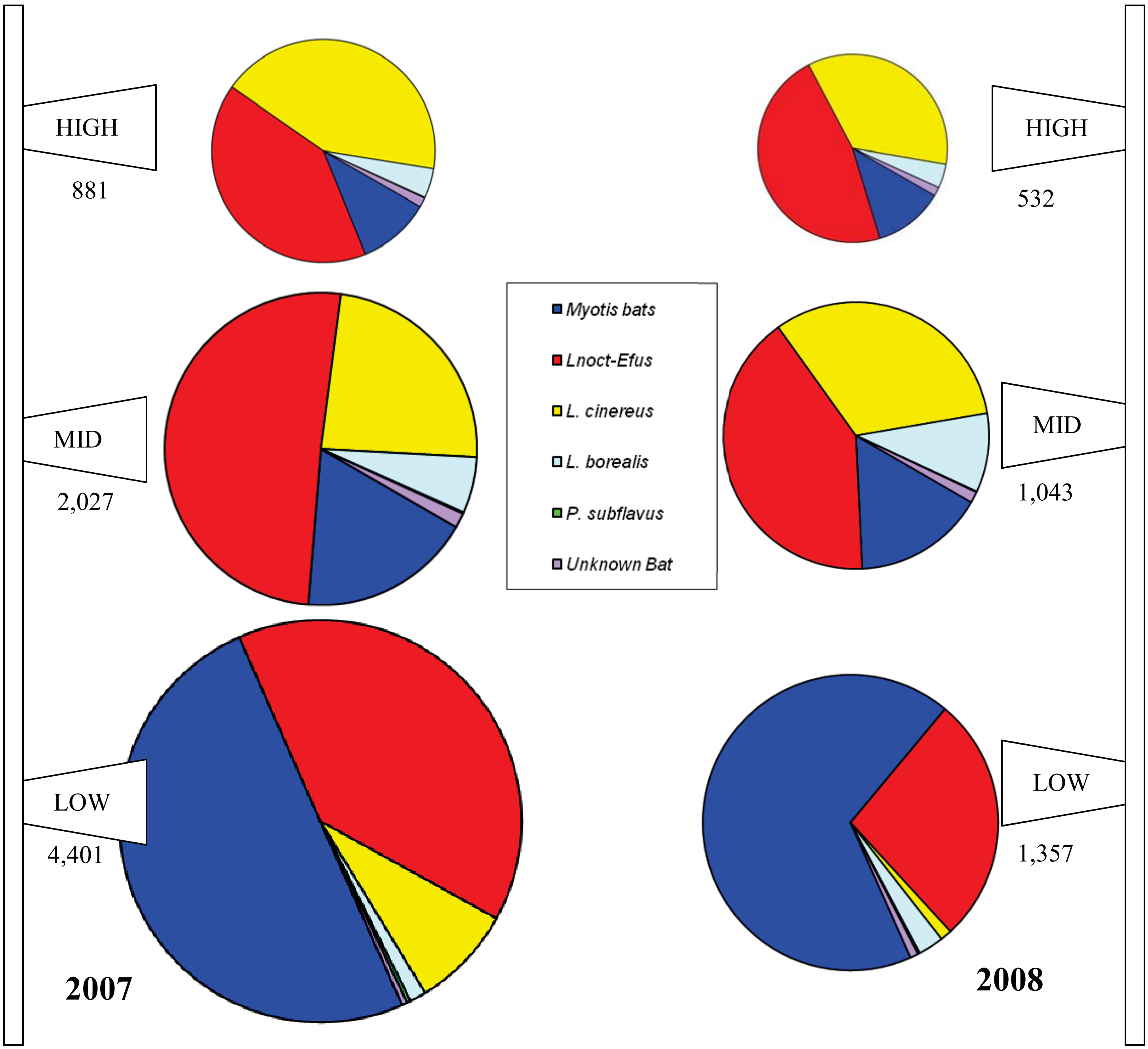


Figure 10. Distribution of Bat Activity across Microphone Heights at Flat Rock Site

The majority of bat activity was heard at the LOW microphone (56.2%) compared to the MID microphone (30.0%) and HIGH microphone (13.8%). Most of this decline in bat activity was due to the reduced *Myotis* activity at the MID and HIGH microphones (Figure 11). When bat activity was standardized by total sampling effort, the LOW microphone had a higher level of activity (12.6 calls/detector-night) than either the MID microphone (6.5 c/dn) or HIGH microphone (3.3 c/dn). This was primarily due to the higher level of *Myotis spp* bat activity at the LOW microphone (6.7 c/dn) compared to either the MID microphone (1.1 c/dn) or HIGH microphone (0.4 c/dn).

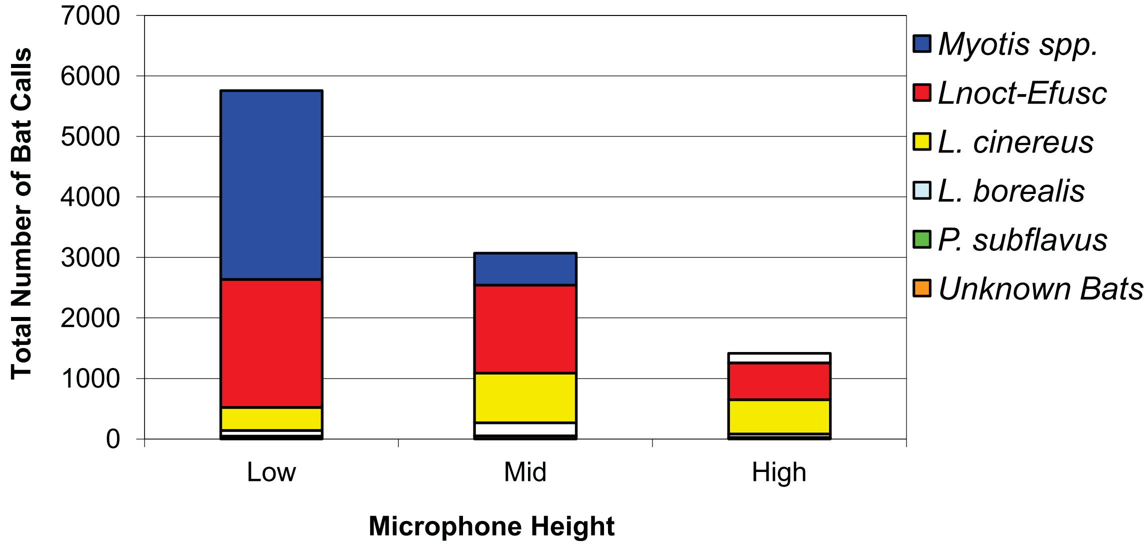


Figure 11. Distribution of Bat Activity At Flat Rock Site (2007 and 2008 combined)

Overall, 81.9% of all *Myotis spp.* bat activity occurred at the LOW microphones, compared to only 13.9% and 4.1% at the MID and HIGH microphones, respectively (Figure 12). Both of the migratory tree bats (*L. cinereus* and *L. borealis*) were more frequently heard at the MID and HIGH microphones relative to the LOW microphones.

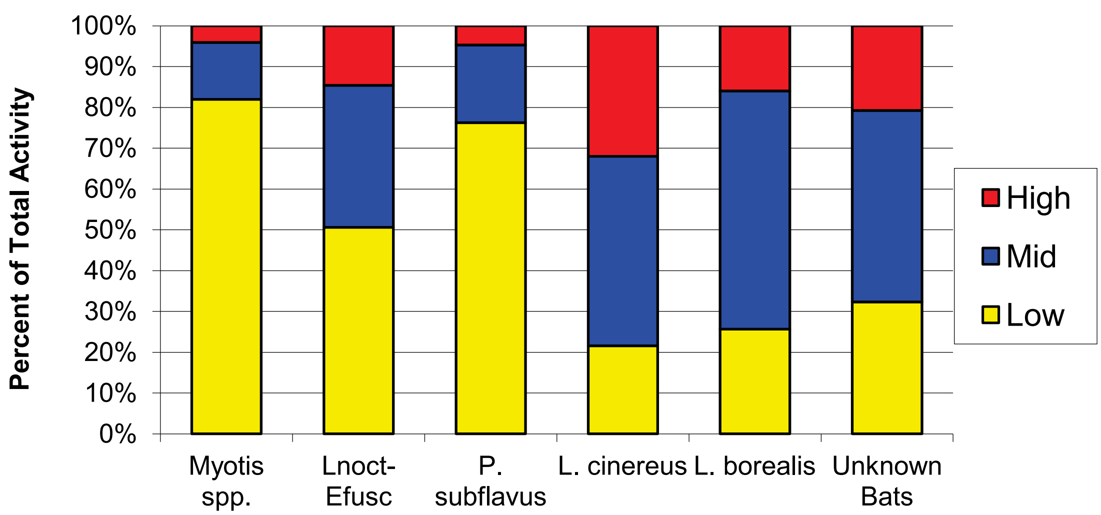


Figure 12. Distribution of Bat Activity by Species at Flat Rock Site (2007 and 2008 combined)

5.3 Flat Rock Site - Low Microphone

During the period from 10 May through 15 December, 2007, a total of 13,257 files were recorded and analyzed. During the period from 30 March through 30 November, 2008, a total of 3,349 files were recorded and analyzed. It was determined that 4,401 and 1,347 files were of bat origin in 2007 and 2008, respectively. A minimum of five species or species groups were detected at the LOW microphone. The *Myotis* bats group was the dominant group heard at the LOW microphone, comprising 50.1% and 67.7% in 2007 and 2008, respectively (Figure 13). The silver-haired/big brown group (*Lnoct-Efusc*) was the second-most abundant bat, comprising 39.7% and 27.1% of all calls.

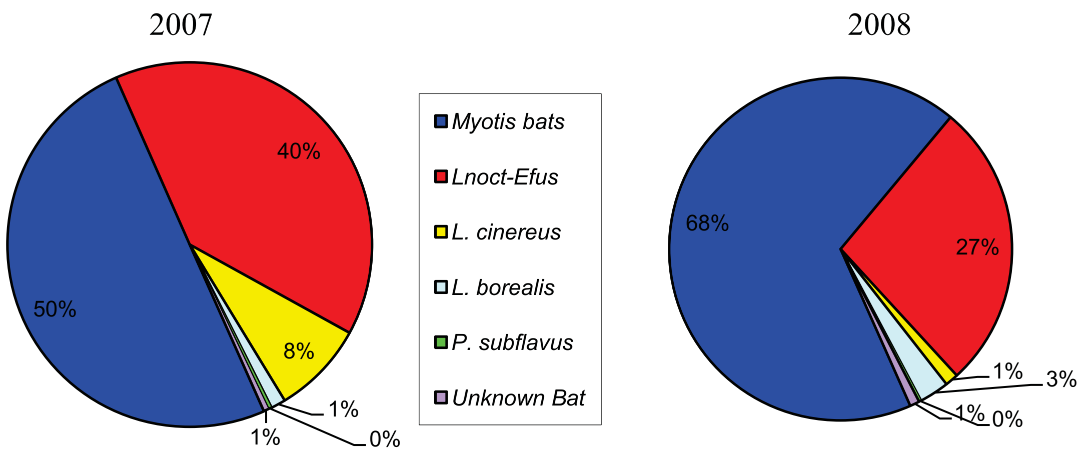


Figure 13. Distribution of Bat Activity by Species at the Flat Rock LOW Microphone

The timing of bat activity was similar across both years, although the magnitude of bat activity was significantly lower in 2008 (Figure 14). Peak bat activity in 2007 occurred during the 7-day period beginning on 23 July, whereas peak bat activity in 2008 began on 01 September. There were two high-activity events in 2007, identified in Figure 14 as the yellow bars. These two days had a total of 401 calls (23 July) and 535 calls (09 Sept). It appears the fall migratory activity was slightly later in 2008 relative to 2007 but the difference in magnitude of bat activity makes it difficult to quantify this pattern. In both years, bat activity at the LOW microphone had virtually ceased by mid-October.

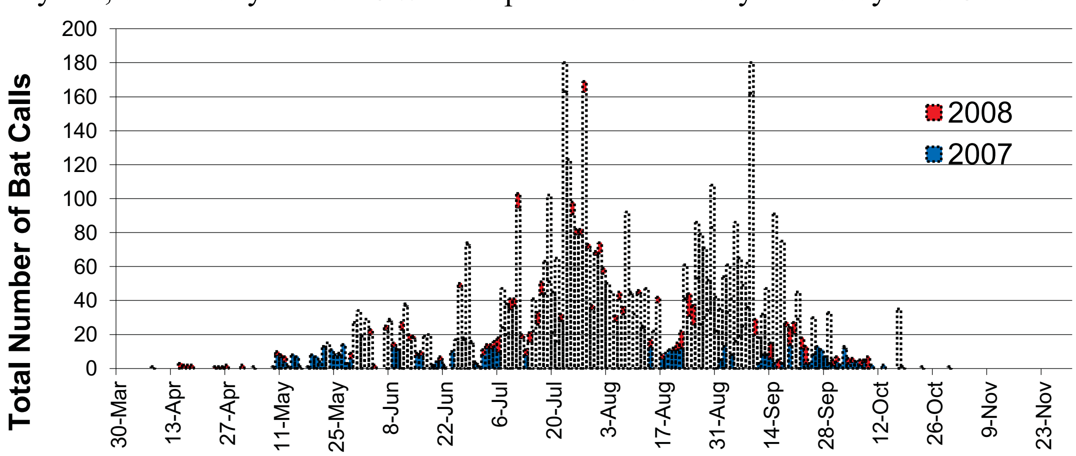


Figure 14. Temporal Distribution in Bat Activity at the Flat Rock LOW Microphone (yellow bars represent high activity nights where data bars were truncated to maintain overall patterns)

5.4 Flat Rock Site - Mid Microphone

During the period from 10 May through 15 December, 2007, a total of 8,915 files were recorded and analyzed. During the period from 30 March through 30 November, 2008, a total of 9,783 files were recorded and analyzed. It was determined that 2,027 and 1,043 files were of bat origin in 2007 and 2008, respectively. A minimum of five species or species groups were detected at the MID microphone. The silver-haired/big brown group (*Lnoct-Efusc*) was the dominant bat group heard at the MID microphone, comprising 50.8% and 40.8% in 2007 and 2008, respectively (Figure 15). The hoary bats (*L. cinereus*) were the second-most abundant bats, comprising 23.8% and 32.2% of all calls, respectively. Across the two-year sampling period, *Myotis spp.* accounted for 17.3% of all bat activity heard at the MID microphone.

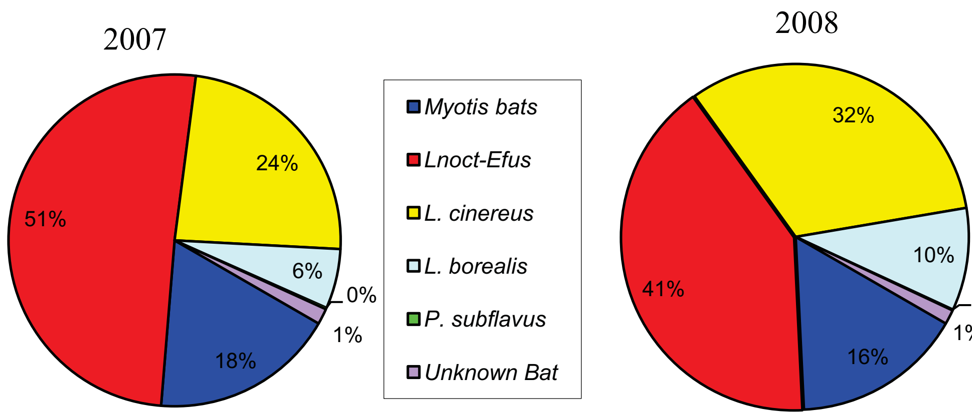


Figure 15. Distribution of Bat Activity by Species at the Flat Rock MID Microphone

The activity levels were consistent between years (Figure 16). Bat activity in 2008 appears to begin earlier than activity in 2007, but this was an artifact of the sampling period, which began on 10 May, 2007 and 30 March, 2008. Peak bat activity, measured as the 7-day period with highest bat activity, began on 22 July in 2007 and 25 July in 2008. There was one high-activity event in 2007, identified in Figure 16 as the yellow bar; there were 163 bat calls identified on 24 July, 2007. In both years, bat activity at the MID microphone had ceased by mid-October.

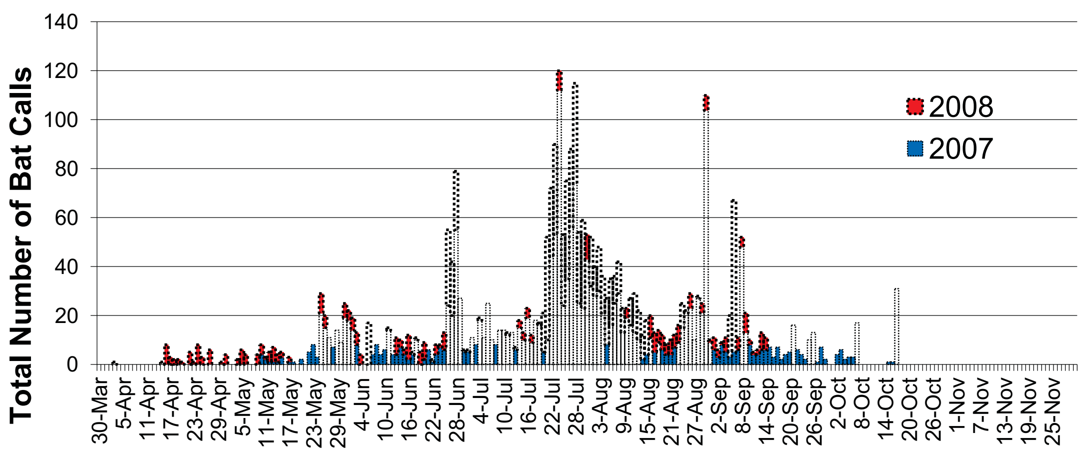


Figure 16. Temporal Distribution in Bat Activity at the Flat Rock MID Microphone (yellow bar represent high activity night where data bar was truncated to maintain overall pattern)

5.5 Flat Rock Site - High Microphone

During the period from 10 May through 15 December, 2007, a total of 32,917 files were recorded and analyzed. During the period from 30 March through 30 November, 2008, a total of 19,130 files were recorded and analyzed. It was determined that 881 and 532 files were of bat origin in 2007 and 2008, respectively. A minimum of five species or species groups were detected at the HIGH microphone. The silver-haired/big brown group (*Lnoct-Efusc*) was the dominant bat group heard at the HIGH microphone, comprising 40.9% and 47.0% in 2007 and 2008, respectively (Figure 17). The hoary bats (*L. cinereus*) were the second-most abundant bats, comprising 42.8% and 35.3% of all calls, respectively. Across the two-year sampling period, *Myotis spp.* accounted for 11.1% of all bat activity heard at the HIGH microphone.

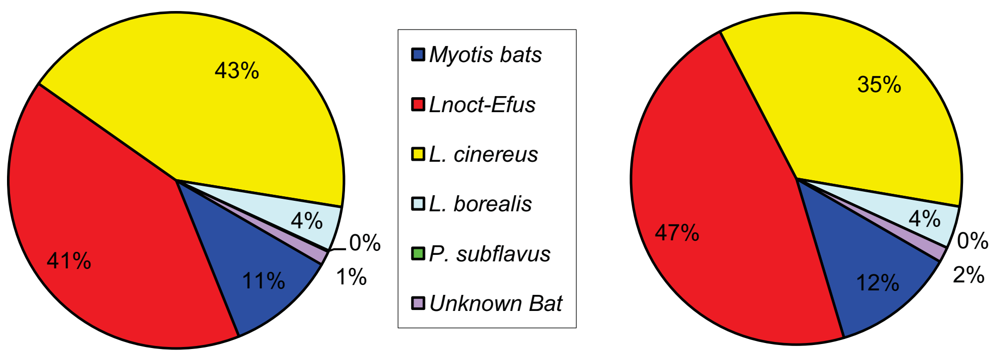


Figure 17. Distribution of Bat Activity by Species at the Flat Rock HIGH Microphone

The timing of bat activity was very similar across both years but 2007 saw substantially more bat activity levels than were evident in 2008 (Figure 18). Bat activity appeared to begin at approximately the same time during both sampling years, although there was substantially more bat activity detected during the summer months in 2007 compared to 2008. Peak fall migratory period, measured as the 7-day period with highest bat activity during the fall season, began on 24 August in 2007 and 04 Sept in 2008. In both years, bat activity at the HIGH microphone had ceased by mid-October.

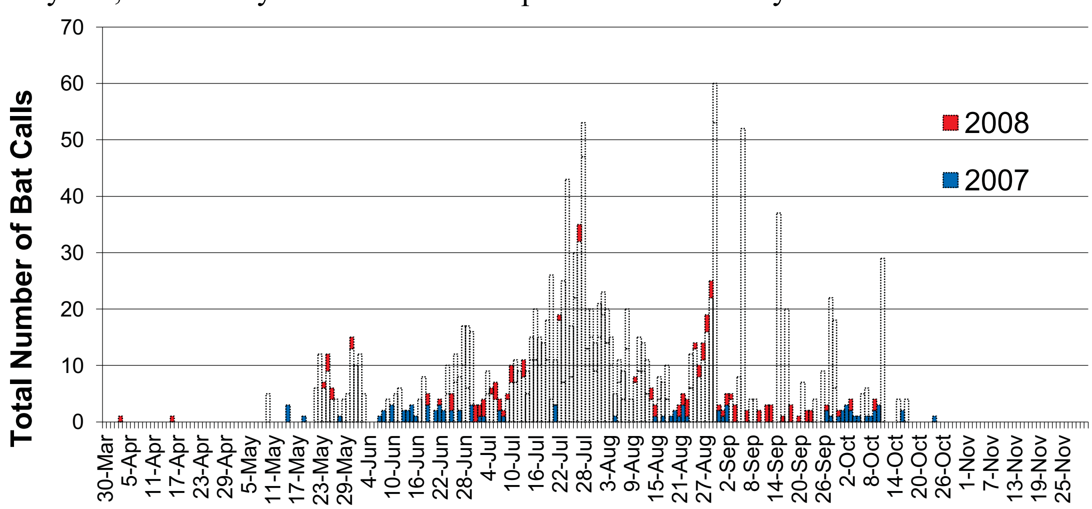


Figure 18. Temporal Distribution in Bat Activity at the Flat Rock HIGH Microphone

6.0 SITE-SPECIFIC DATA - COBB

6.1 Sampling Effort at the Cobb Site

Bat activity was monitored at the Cobb Road Tower site from 10 May through 15 December, 2007 and again from 30 March through 30 November 2008. The total sampling period was 220 days (3,080 hours per detector) in 2007 and 246 days (3,444 hours per detector) in 2008. Due to the potential for data overload, failure to swap cards, card reading failures, or equipment malfunction, the actual sampling effort of each microphone is generally less than this maximal potential sampling effort. The sampling effort at the MRWP project site is summarized in Table 4. Although the sampling efficiency appears relatively low (71.6% overall), all of the system failures occurred at the end of the monitoring period, and 80.2% of the data loss was outside of any peak activity periods; limiting the analysis to the peak activity periods, overall sampling efficiency was 86.3% in 2007 and 96.5% in 2008.

Table 4. Acoustic Sampling Effort at the Cobb Tower Site

	Microphone	Total Days Monitoring	Percent of Total Monitoring	Reasons for Data Loss (days of loss)
2007	LOW	125	56.8%	system failure (95)
	MID	114	51.8%	card failure (10) system failure (96)
	HIGH	210	95.5%	card failure (10)
	AVERAGE	**149.7**	**68.0%**	
2008	LOW	166	67.5%	system failure (80)
	MID	194	78.9%	system failure (52)
	HIGH	194	78.9%	system failure (52)
	AVERAGE	**184.7**	**75.1%**	
OVERALL	**AVERAGE**	**167.2**	**71.6%**	

6.2 Summary of Data Collected at the Cobb Site

A total of 95,141 files was recorded by the acoustic monitoring equipment. After analysis, 5,573 files (5.9%) were determined to be of bat origin. Although the vast majority of the acoustical activity was wind noise, there were some files that appeared to be mechanical and non-bat biological in origin. Combining data from all microphones, bat activity was documented on 137 of the sampling days in 2007 (62.3%) and 149 of the sampling days in 2008 (63.1%); within the peak activity periods, bat activity was detected on 87.5% of the sampling nights. A depiction of overall bat activity at the Cobb

Site is shown in Figure 19. Each pie graph is scaled to represent total relative activity (with actual bat calls identified by the numbers next to each graph).

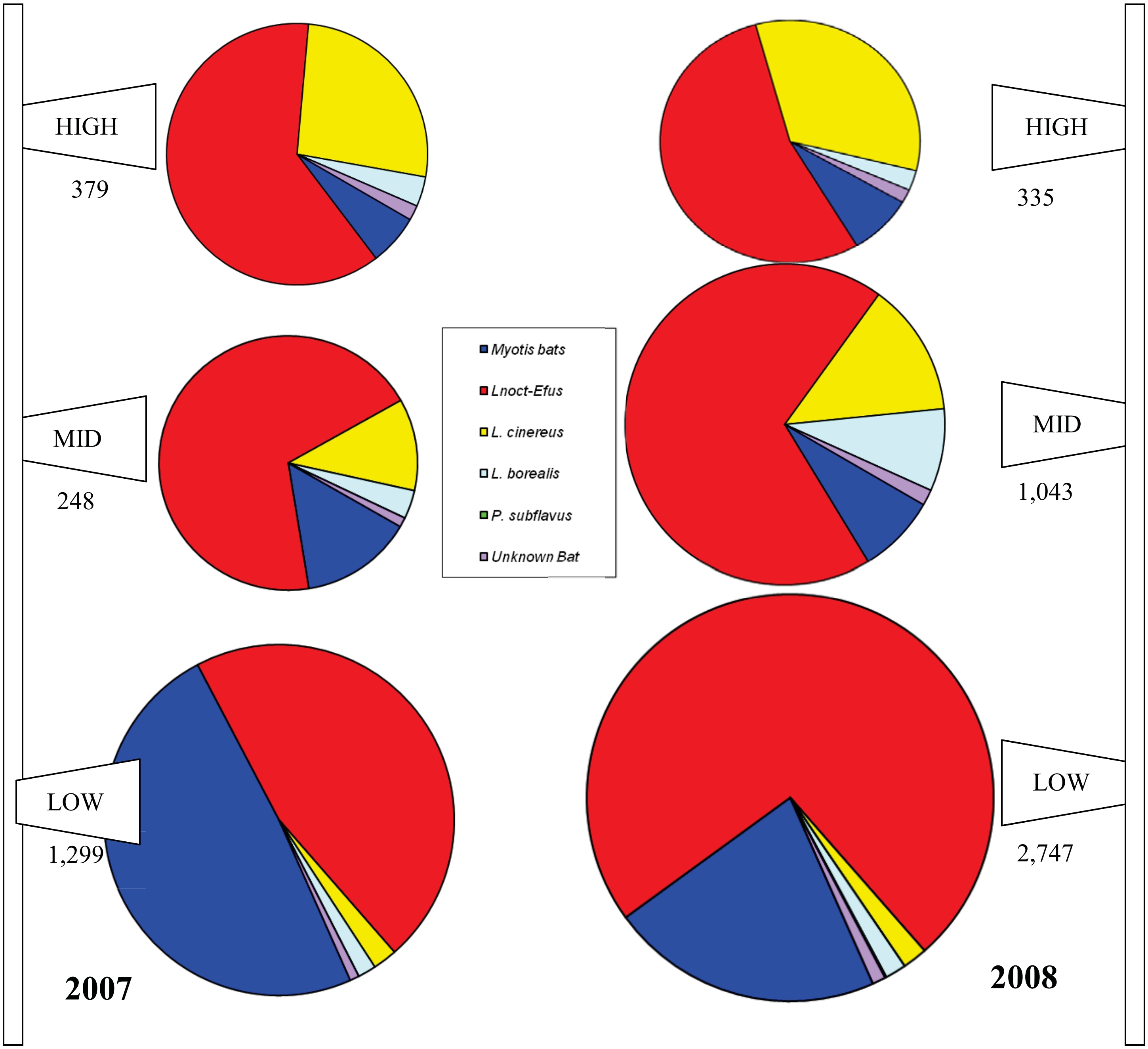


Figure 19. Distribution of Bat Activity across Microphone Heights at Cobb Site

6.3 Cobb Site - Low Microphone

During the period from 10 May through 15 December, 2007, a total of 26,632 files were recorded and analyzed. During the period from 30 March through 30 November, 2008, a total of 20,993 files were recorded and analyzed. It was determined that 1,299 and 2,747 files were of bat origin in 2007 and 2008, respectively. A minimum of five species or species groups were detected at the LOW microphone. The *Myotis* bats were the dominant bat group heard at the LOW microphone, comprising 49.0% and 21.7% in 2007 and 2008, respectively (Figure 20). The silver-haired/big brown group (*Lnoct-Efusc*) were equally abundant across the two years, comprising 46.3% and 73.5% of all calls, respectively.

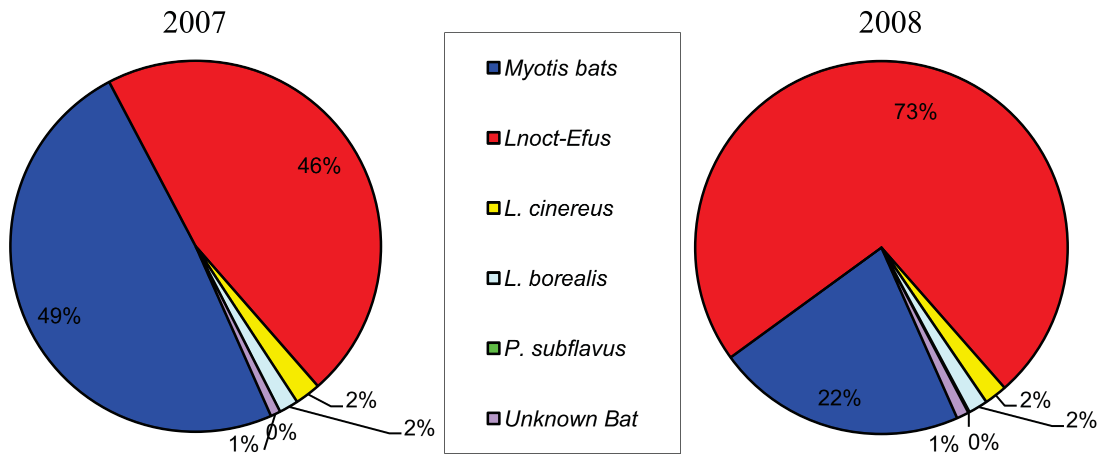


Figure 20. Distribution of Bat Activity by Species at the Cobb LOW Microphone

The timing of bat activity was very similar across both years but 2008 saw substantially more bat activity levels during the early fall migratory period (Figure 21). Bat activity appeared to begin at approximately the same time during both sampling years, although there was substantially more bat activity detected during the summer months in 2007 compared to 2008. Peak fall migratory period, measured as the 7-day period with highest bat activity during the fall, began on 02 August in both sample years.

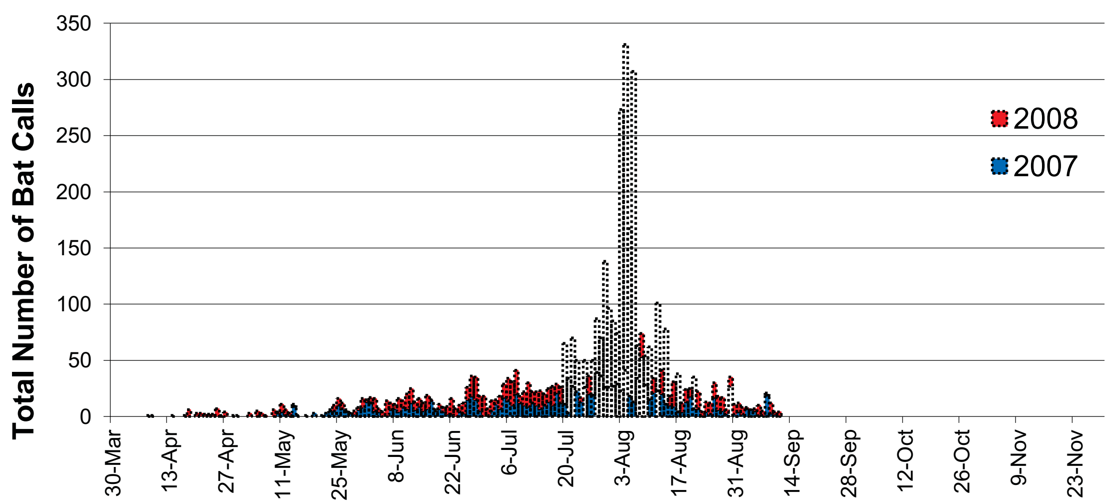


Figure 21. Temporal Distribution in Bat Activity at the Cobb LOW Microphone

6.4 Cobb Site - Mid Microphone

During the period from 10 May through 15 December, 2007, a total of 15,130 files were recorded and analyzed. During the period from 30 March through 30 November, 2008, a total of 8,575 files were recorded and analyzed. It was determined that 248 and 565 files were of bat origin in 2007 and 2008, respectively. A minimum of five species or species groups were detected at the MID microphone. The silver-haired/big brown group (*Lnoct-Efusc*) were the dominant bat group heard at the MID microphone, comprising 69.4% and 68.7% in 2007 and 2008, respectively (Figure 22). Across the two years, the *Myotis* bats and the hoary bat (*L. cinereus*) were equally abundant, comprising 9.8% and 12.9% of all calls, respectively.

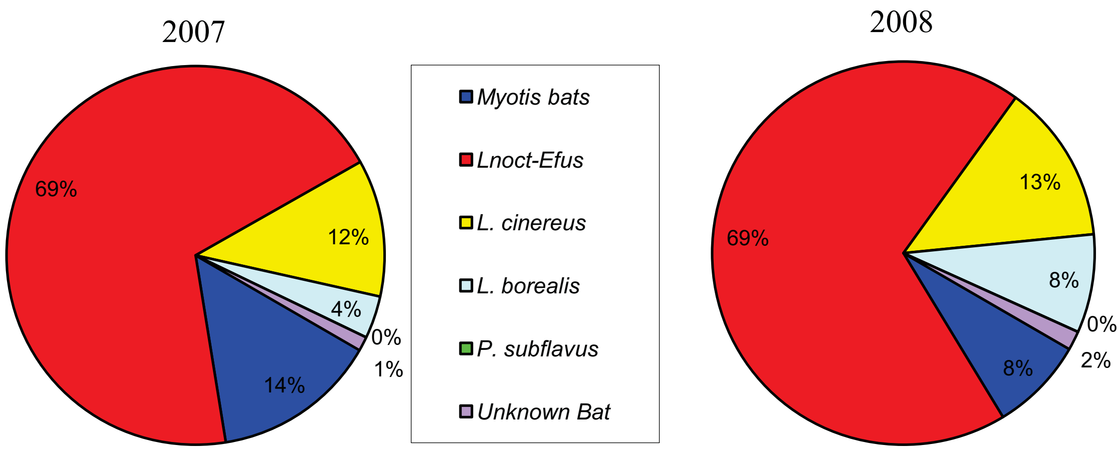


Figure 22. Distribution of Bat Activity by Species at the Cobb MID Microphone

The timing of bat activity was very similar across both years but 2008 saw approximately twice as much bat activity as 2007; this increased activity appeared to be consistent across the sampling period. (Figure 23). Peak fall migratory period, measured as the 7-day period with highest bat activity during the fall season, began on 02 August in both sample years; this is the exact same timing as documented at the Cobb MID microphone.

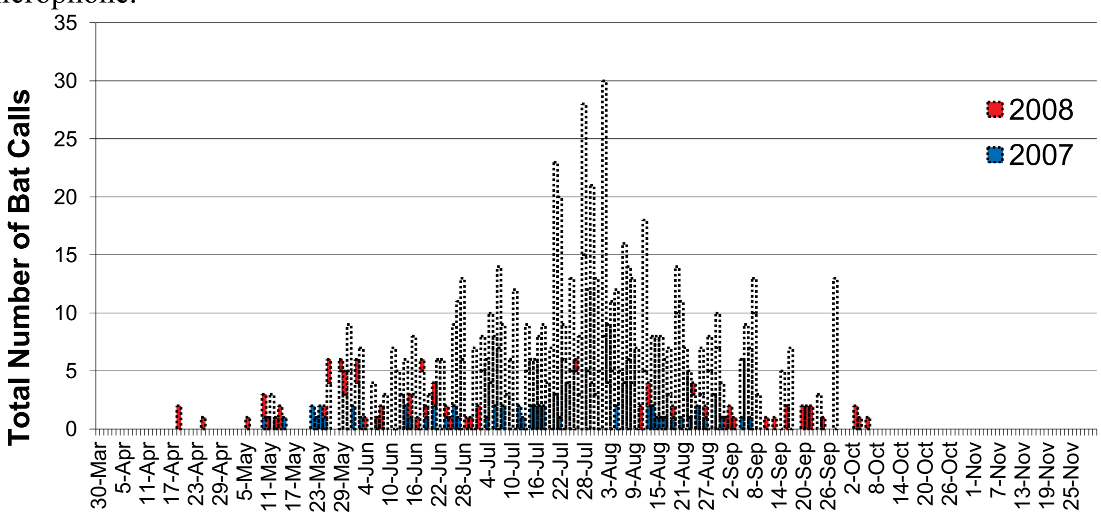


Figure 23. Temporal Distribution in Bat Activity at the Cobb MID Microphone

6.5 Cobb Site - High Microphone

During the period from 10 May through 15 December, 2007, a total of 16,858 files were recorded and analyzed. During the period from 30 March through 30 November, 2008, a total of 6,944 files were recorded and analyzed. It was determined that 379 and 335 files were of bat origin in 2007 and 2008, respectively. A minimum of four species or species groups were detected at the HIGH microphone. The silver-haired/big brown group (*Lnoct-Efusc*) were the dominant bat group heard at the HIGH microphone, comprising 61.7% and 54.3% in 2007 and 2008, respectively (Figure 24). The hoary bat (*L. cinereus*) was the second most abundant species, comprising 26.4% and 33.1% in 2007 and 2008, respectively.

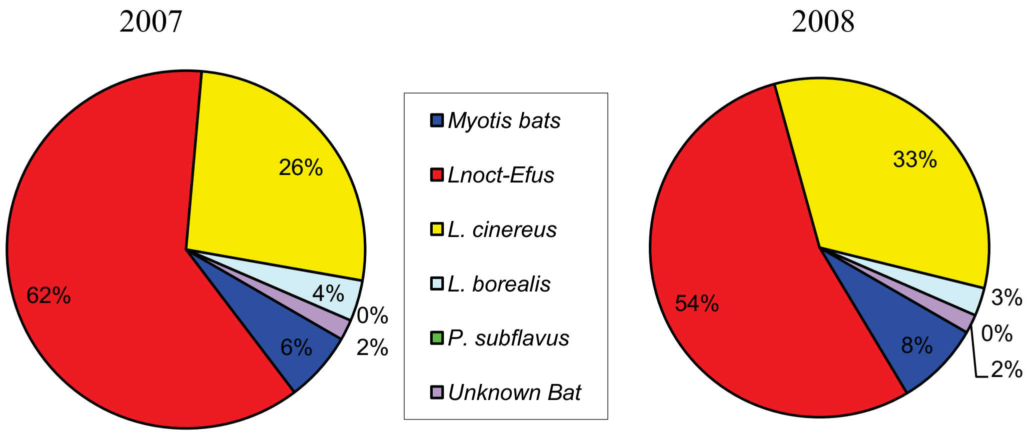


Figure 24. Distribution of Bat Activity by Species at the Cobb HIGH Microphone

The timing of bat activity at the Cobb HIGH microphone was similar in both timing and magnitude (Figure 25). Peak fall migratory period, measured as the 7-day period with highest bat activity during the fall season, began on 04 August in 2007, but did not occur until 03 September in 2008. This was primarily due to a single high-activity event in 2008, identified in Figure 25 as the yellow bar. Specifically, there were 47 bat calls identified on 06 September, 2008; this is more than twice as many calls heard on any single day across the entire sampling period at the Cobb HIGH microphone.

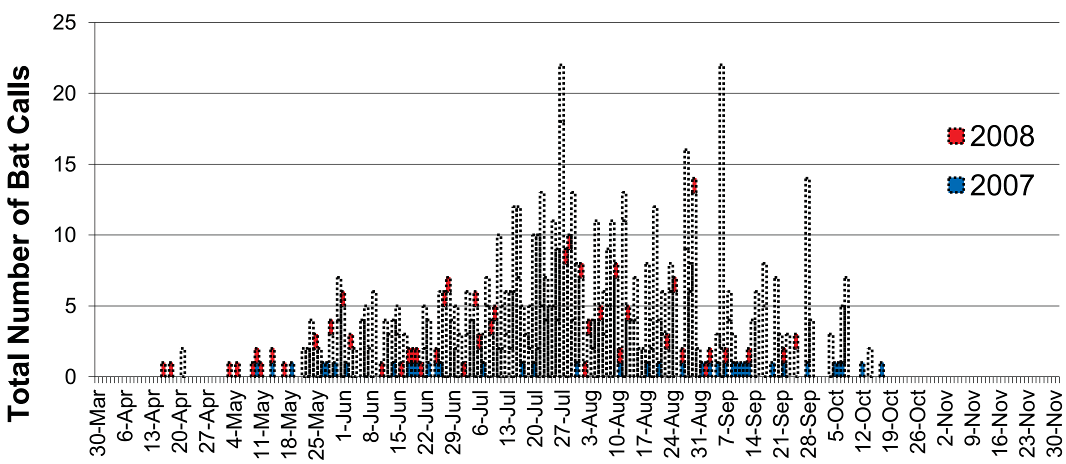


Figure 25. Temporal Distribution in Bat Activity at the Cobb HIGH Microphone(yellow bar represent high activity night where data bar was truncated to maintain overall pattern)

7.0 SITE-SPECIFIC DATA - GARDNER

7.1 Sampling Effort at the Gardner Site

Bat activity was monitored at the Gardner Road Tower site from 10 May through 15 December, 2007 and again from 30 March through 30 November 2008. The total sampling period was 220 days (3,080 hours per detector) in 2007 and 246 days (3,444 hours per detector) in 2008. Due to the potential for data overload, failure to swap cards, card reading failures, or equipment malfunction, the actual sampling effort of each microphone is generally less than this maximal potential sampling effort. The sampling effort at the MRWP project site is summarized in Table 5. Although the sampling efficiency appears relatively low (67.2% overall), many of the system failures occurred at the end of the monitoring period. Limiting the analysis to the peak activity periods, overall sampling efficiency was 74.5% in 2007 and 74.8% in 2008.

Table 5. Acoustic Sampling Effort at the Gardner Tower Site

	Microphone	Total Days Monitoring	Percent of Total Monitoring	Reasons for Data Loss (days of loss)
2007	LOW	64	29.0%	card overload (38) system failure (118)
	MID	220	100.0%	
	HIGH	119	54.1%	system failure (101)
	AVERAGE	**134.3**	**61.1%**	
2008	LOW	110	44.7%	card failure (42) card overload (11) system failure (83)
	MID	234	95.1%	card overload (12)
	HIGH	193	78.4%	card overload (8) system failure (45)
	AVERAGE	**179.0**	**72.8%**	
OVERALL	**AVERAGE**	**156.7**	**67.2%**	

7.2 Summary of Data Collected at the Gardner Site

A total of 244,663 files was recorded by the acoustic monitoring equipment. After analysis, 3,289 files (1.3%) were determined to be of bat origin. Although the vast majority of the acoustical activity was wind noise, there were some files that appeared to be mechanical and non-bat biological in origin. Combining data from all microphones, bat activity was documented on 132 of the sampling days in 2007 (60.0%) and 145 of the sampling days in 2008 (58.9%); within the peak activity periods, bat activity was detected on 83.1% of the sampling nights. A depiction of overall bat activity at the

Gardner Site is shown in Figure 26. Each pie graph is scaled to represent total relative activity (with actual bat calls identified by the numbers next to each graph).

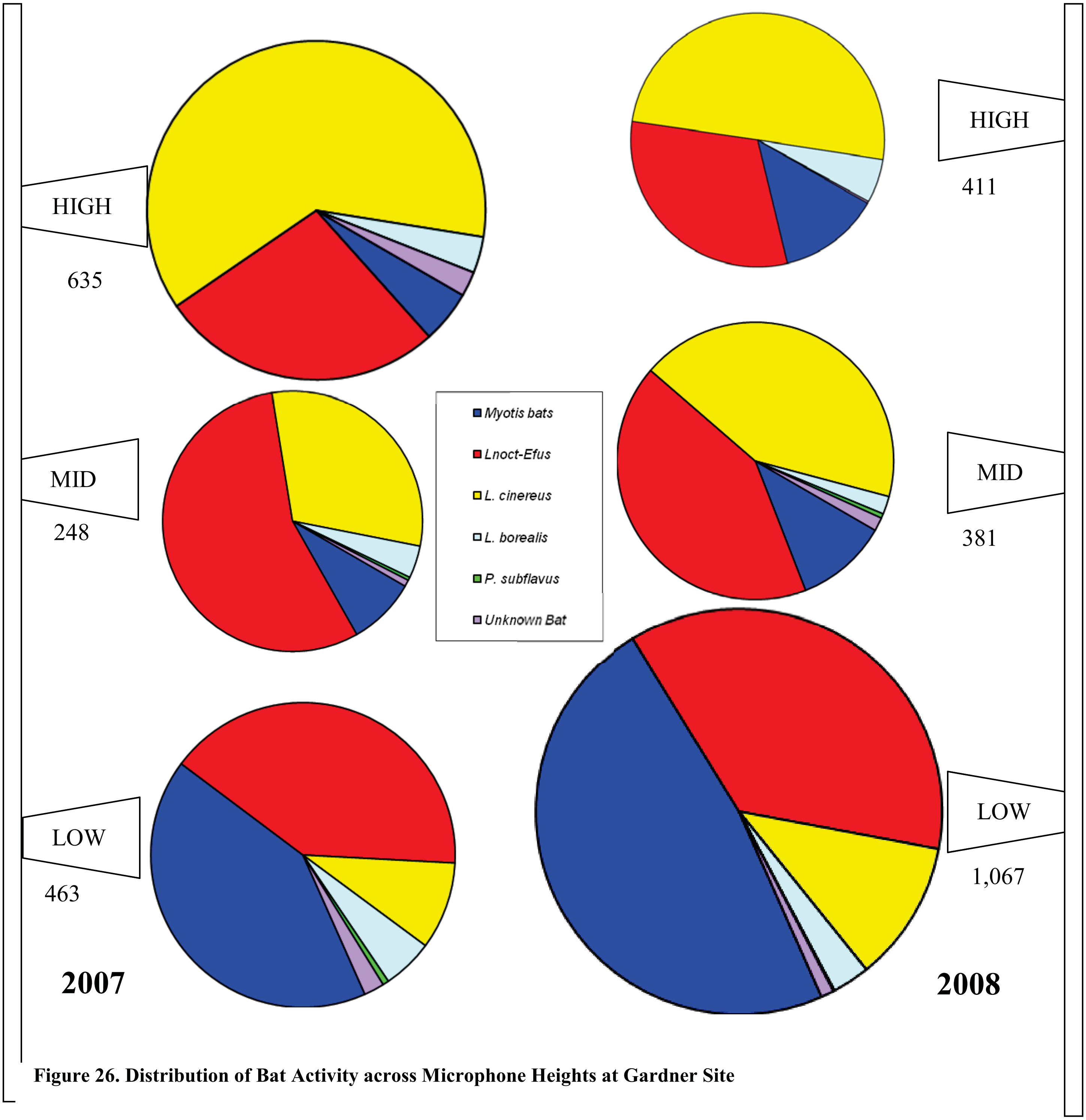


Figure 26. Distribution of Bat Activity across Microphone Heights at Gardner Site

7.3 Gardner Site - Low Microphone

During the period from 10 May through 15 December, 2007, a total of 50,472 files were recorded and analyzed. During the period from 30 March through 30 November, 2008, a total of 17,810 files were recorded and analyzed. It was determined that 463 and 1,067 files were of bat origin in 2007 and 2008, respectively. A minimum of five species or species groups were detected at the LOW microphone. The *Myotis* bats were the dominant bat group heard at the LOW microphone, comprising 41.9% and 47.9% in 2007 and 2008, respectively (Figure 27). The silver-haired/big brown group (*Lnoct-Efusc*) were equally abundant, comprising 40.6% and 36.7% of all calls.

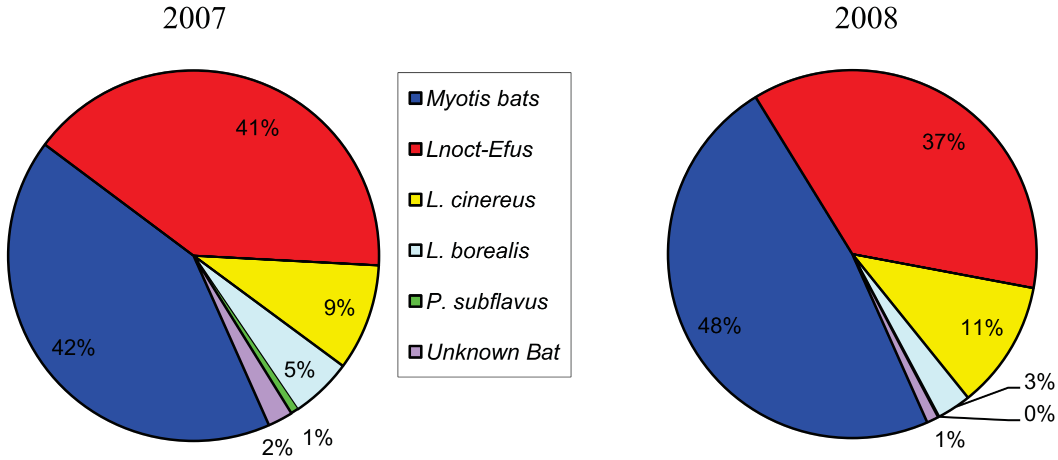


Figure 27. Distribution of Bat Activity by Species at the Gardner LOW Microphone

The bat activity at the Gardner LOW microphone appears to be similar in both timing and magnitude between the two years despite the data gaps during the 2007 sampling period (Figure 28). Peak fall migratory period, measured as the 7-day period with highest bat activity during the fall season, began on 06 August in 2007, but did not occur until 31 August in 2008; the delay in peak activity in 2008 was primarily due to a single high-activity event in 2008 (103 calls on 06 September). Summer activity levels appear to be very consistent at the LOW microphone between the two sampling years.

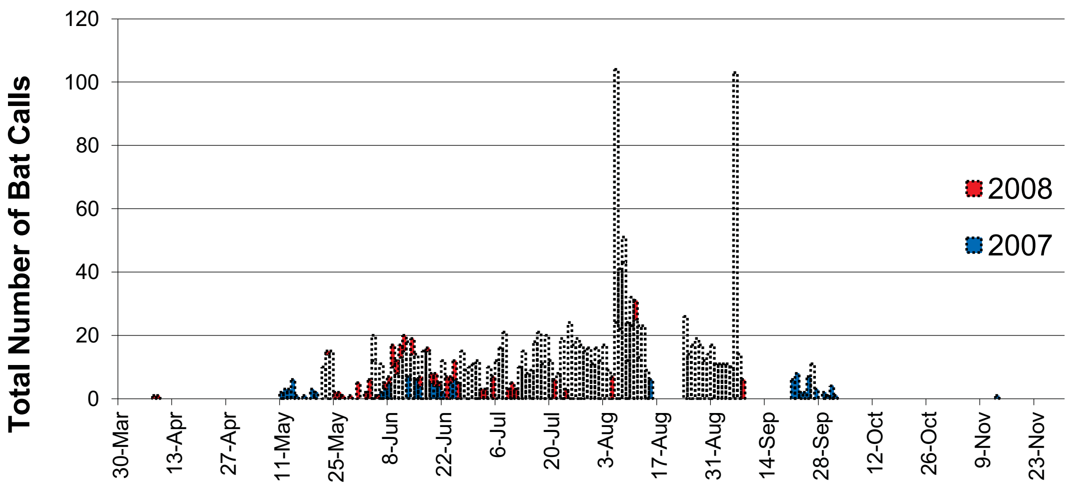


Figure 28. Temporal Distribution in Bat Activity at the Gardner LOW Microphone

7.4 Gardner Site - Mid Microphone

During the period from 10 May through 15 December, 2007, a total of 21,214 files were recorded and analyzed. During the period from 30 March through 30 November, 2008, a total of 94,017 files were recorded and analyzed. It was determined that 248 and 381 files were of bat origin in 2007 and 2008, respectively. A minimum of five species or species groups were detected at the MID microphone. The silver-haired/big brown group (*Lnoct-Efusc*) was the dominant bat group heard at the MID microphone, comprising 55.6% and 42.3% in 2007 and 2008, respectively (Figure 29). The hoary bat (*L. cinereus*) was the second-most abundant bat across the two years, comprising 30.6% and 42.8% of all calls, respectively.

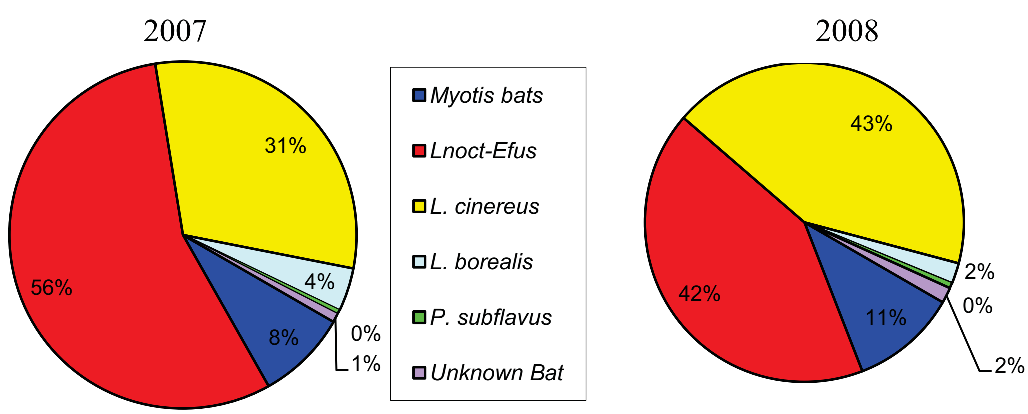


Figure 29. Distribution of Bat Activity by Species at the Gardner MID Microphone

The timing of bat activity at the Gardner MID microphone was similar in both timing and magnitude, although there was slightly more summer bat activity in 2008 (Figure 30). Peak fall migratory period, measured as the 7-day period with highest bat activity during the fall season, began on 07 August in 2007 and 05 August, 2008. The single highest-activity day was 20 calls on 20 July, 2008.

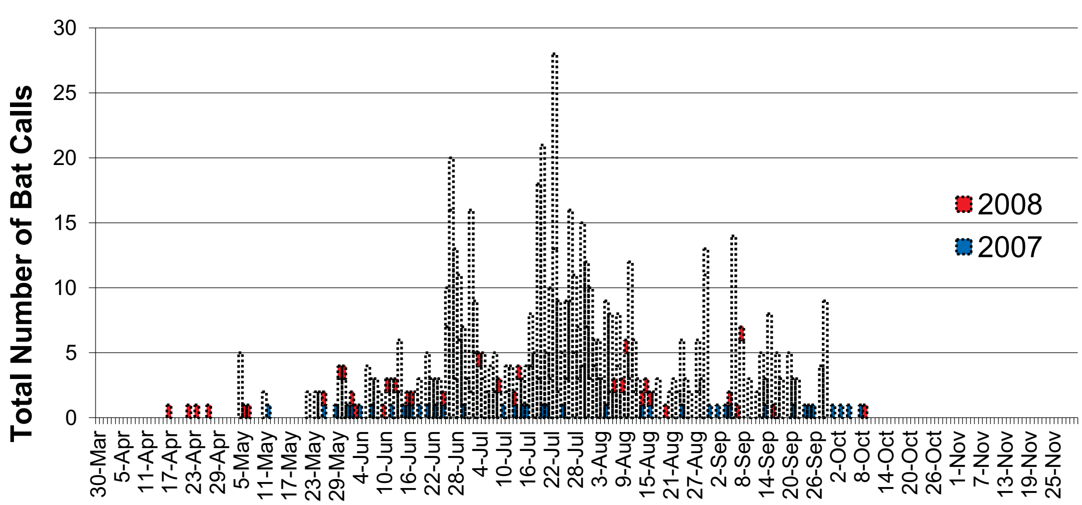


Figure 30. Temporal Distribution in Bat Activity at the Gardner MID Microphone

7.5 Gardner Site - High Microphone

During the period from 10 May through 15 December, 2007, a total of 19,438 files were recorded and analyzed. During the period from 30 March through 30 November, 2008, a total of 43,197 files were recorded and analyzed. It was determined that 635 and 411 files were of bat origin in 2007 and 2008, respectively. A minimum of four species or species groups were detected at the HIGH microphone. The hoary bat (*L. cinereus*) was the dominant bat heard at the HIGH microphone, comprising 62.0% and 50.1% in 2007 and 2008, respectively (Figure 31). The silver-haired/big brown group (*Lnoct-Efusc*) was the second-most abundant species group across the two years, comprising 27.1% and 31.1% of all calls, respectively.

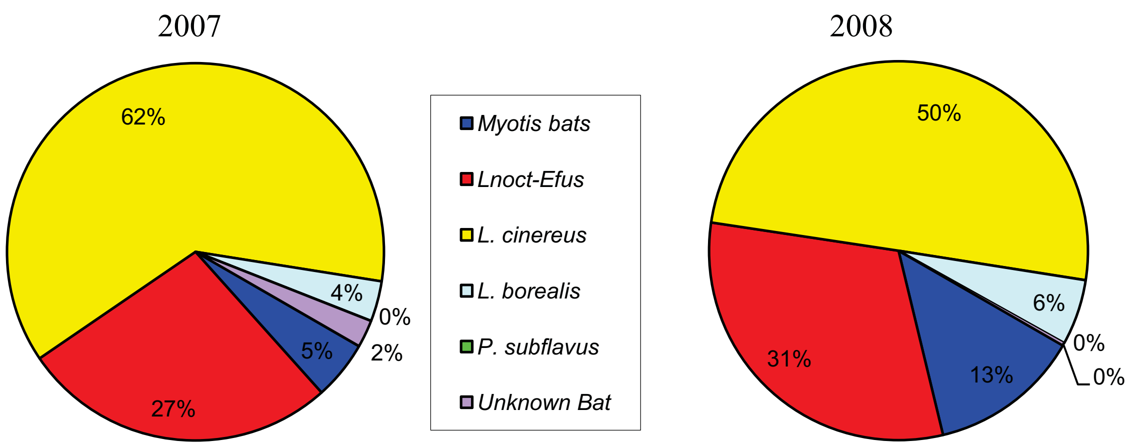


Figure 31. Distribution of Bat Activity by Species at the Gardner HIGH Microphone

The timing of bat activity at the Cobb HIGH microphone was similar in both timing and magnitude, although there was more overall bat activity in 2007 (Figure 32). Peak fall migratory period, measured as the 7-day period with highest bat activity during the fall season, began on 01 August in 2007 and 02 August, 2008. The peak activity period for the entire sampling period was 22 July for 2007 and 19 July for 2008.

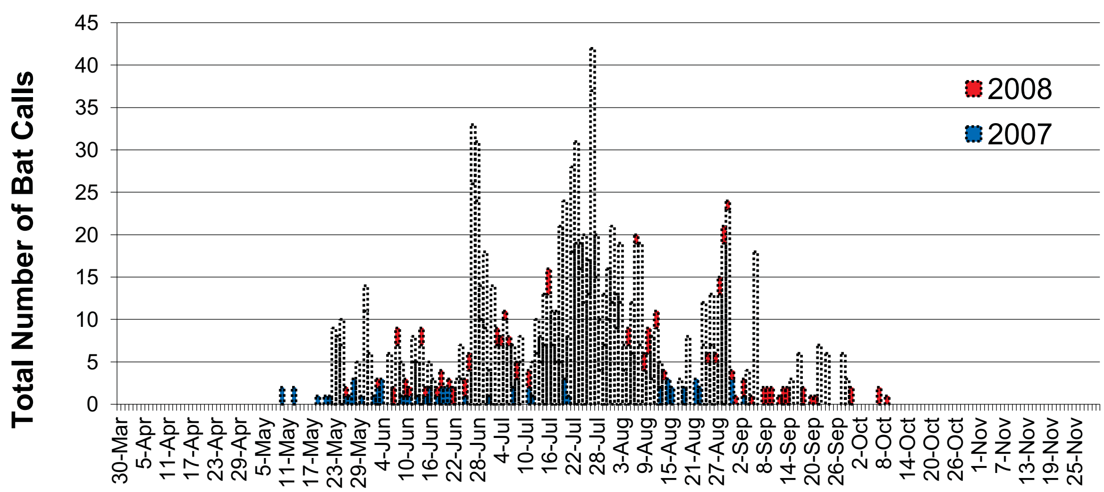


Figure 32. Temporal Distribution in Bat Activity at the Gardner HIGH Microphone

8.0 SITE-SPECIFIC DATA - PORTER

8.1 Sampling Effort at the Porter Site

Bat activity was monitored at the Porter Road Tower site from 10 May through 15 December, 2007 and again from 30 March through 09 June 2008. The total sampling period was 220 days (3,080 hours per detector) in 2007 and 72 days (1,008 hours per detector) in 2008. The reduced sampling period in 2008 was due to failures with the tower, inaccessibility to the tower site, and logistical concerns about the status of the tower. Due to the potential for data overload, failure to swap cards, card reading failures, or equipment malfunction, the actual sampling effort of each microphone is generally less than this maximal potential sampling effort. The sampling effort at the MRWP project site is summarized in Table 6. Limiting the analysis to the peak activity periods, overall sampling efficiency was 86.3% in 2007 and 78.7% in 2008.

Table 6. Acoustic Sampling Effort at the Porter Road Site

	Microphone	Total Days Monitoring	Percent of Total Monitoring	Reasons for Data Loss (days of loss)
2007	LOW	208	94.5%	card overload (12)
	MID	211	95.9%	card overload (9)
	HIGH	106	54.1%	card overload (19) system failure (95)
	AVERAGE	**175.0**	**79.5%**	
2008	LOW	72	100.0	
	MID	72	100.0%	
	HIGH	26	36.1%	system failure (46)
	AVERAGE	**56.7**	**78.7%**	
OVERALL	**AVERAGE**	**--**	**79.1%**	

8.2 Summary of Data Collected at the Porter Site

A total of 151,460 files was recorded by the acoustic monitoring equipment. After analysis, 888 files (5.8%) were determined to be of bat origin. Although the vast majority of the acoustical activity was wind noise, there were some files that appeared to be mechanical and non-bat biological in origin. Combining data from all microphones, bat activity was documented on 157 of the sampling days in 2007 (71.4%) and 28 of the sampling days in 2008 (38.9%); within the peak activity periods, bat activity was detected on 87.4% of the sampling nights in 2007. A depiction of overall bat activity at the Porter Site is shown in Figure 33. Each pie graph is scaled to represent total relative activity (with actual bat calls identified by the numbers next to each graph).

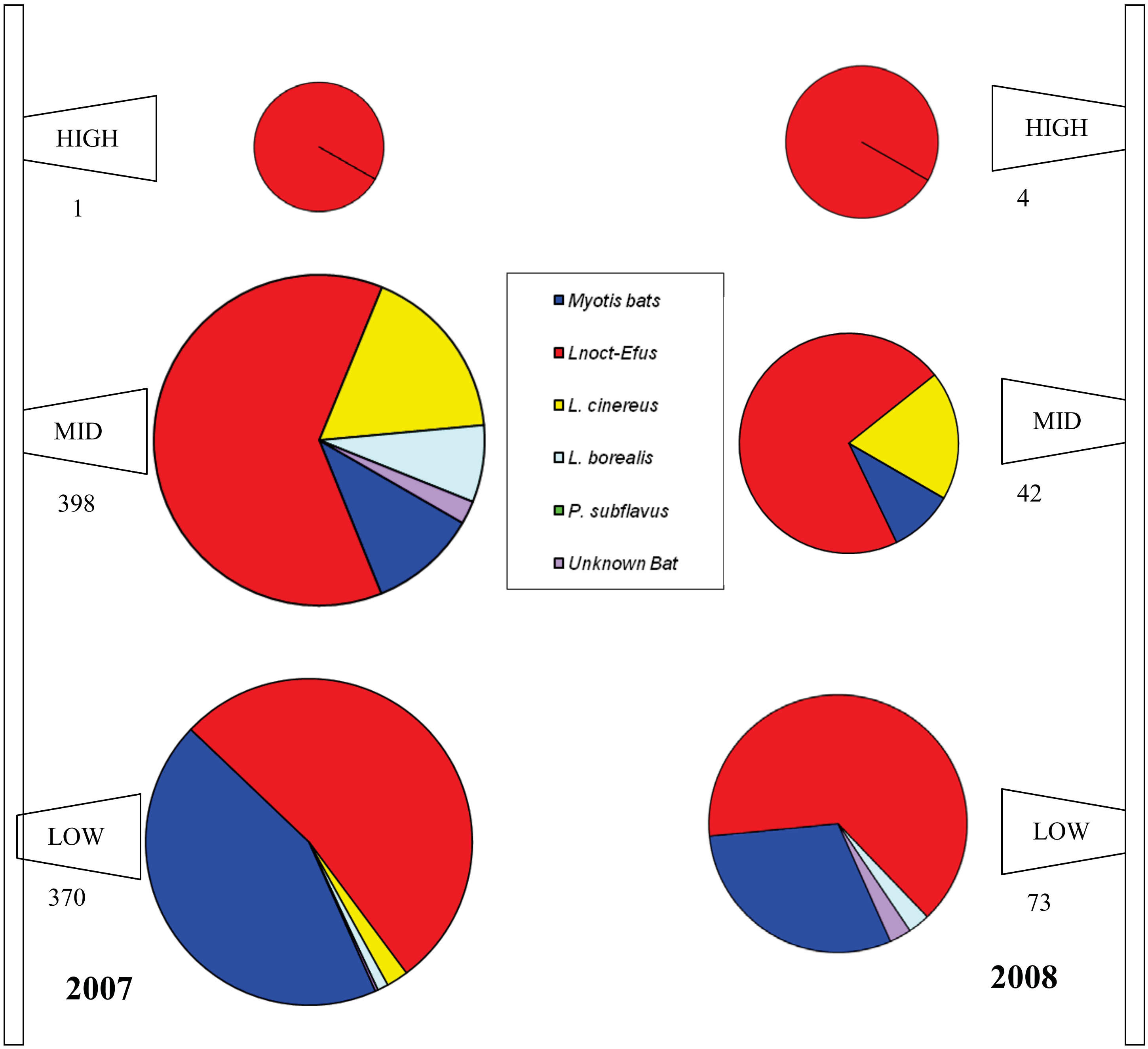


Figure 33. Distribution of Bat Activity across Microphone Heights at Porter Site

8.3 Porter Site - Low Microphone

During the period from 10 May through 15 December, 2007, a total of 9,226 files were recorded and analyzed. During the period from 30 March through 09 June, 2008, a total of 28,808 files were recorded and analyzed. It was determined that 370 and 73 files were of bat origin in 2007 and 2008, respectively. A minimum of four species or species groups were detected at the LOW microphone. The silver-haired/big brown group (*Lnoct-Efusc*) was the dominant bat group heard at the LOW microphone, comprising 52.7% and 64.4% in 2007 and 2008, respectively (Figure 34). *Myotis spp*. were the second-most abundant species group across the two years, comprising 43.8% and 30.1% of all calls.

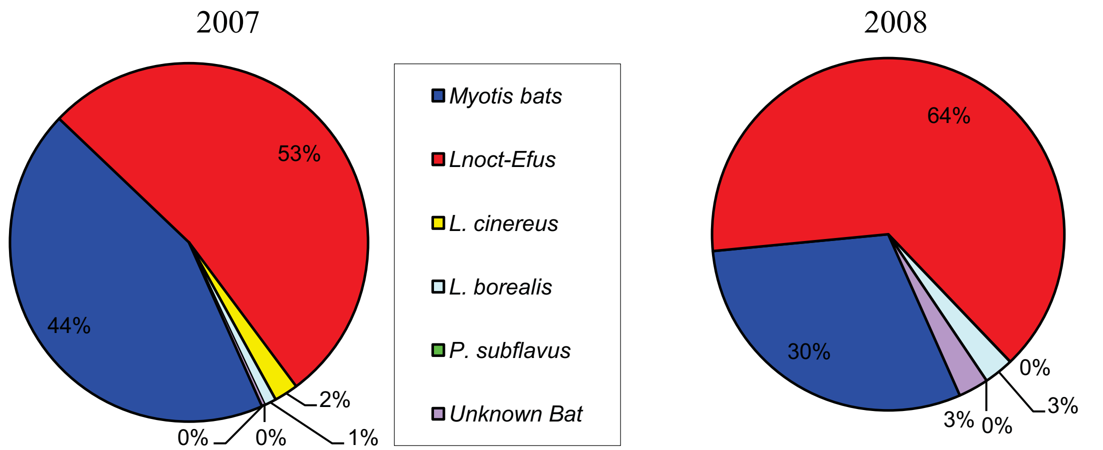


Figure 34. Distribution of Bat Activity by Species at the Porter LOW Microphone

We are only able to characterize the timing of bat activity at the Porter LOW microphone for the 2007 sampling period because of the truncated sampling that occurred in 2008 (Figure 35). Peak fall migratory period, measured as the 7-day period with highest bat activity during the fall season, began on 05 August in 2007, although bat activity was relatively high for the two week period prior to this peak as well.

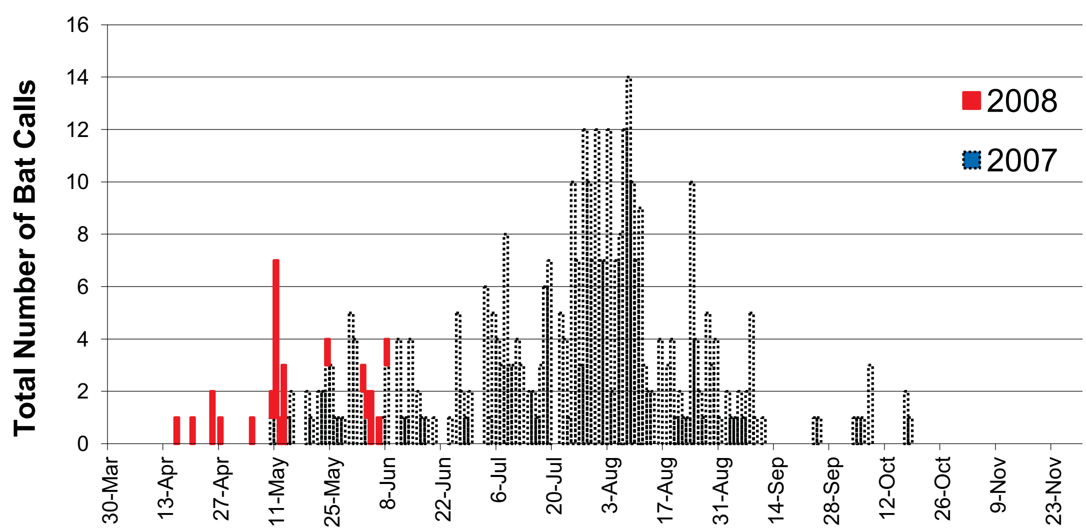


Figure 35. Temporal Distribution in Bat Activity at the Porter LOW Microphone

8.4 Porter Site - Mid Microphone

During the period from 10 May through 15 December, 2007, a total of 24,663 files were recorded and analyzed. During the period from 30 March through 09 June, 2008, a total of 13,951 files were recorded and analyzed. It was determined that 398 and 42 files were of bat origin in 2007 and 2008, respectively. A minimum of four species or species groups were detected at the HIGH microphone. The silver-haired/big brown group (*Lnoct-Efusc*) was the dominant bat group heard at the MID microphone, comprising 62.3% and 71.4% in 2007 and 2008, respectively (Figure 36). The hoary bat (*L. cinereus*) was the second-most abundant species group across the two years, comprising 17.3% and 19.0% of all calls, respectively.

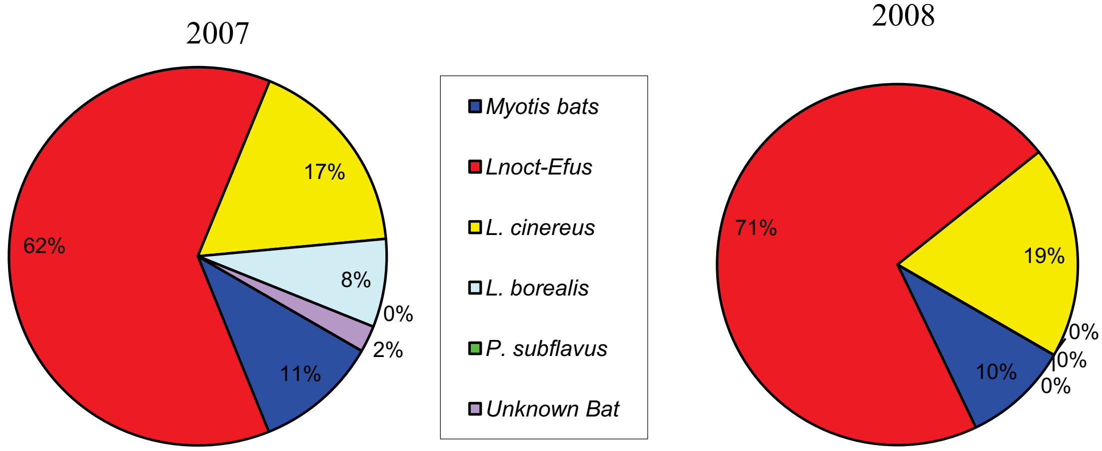


Figure 36. Distribution of Bat Activity by Species at the Porter MID Microphone

We are only able to characterize the timing of bat activity at the Porter MID microphone for the 2007 sampling period because of the truncated sampling that occurred in 2008 (Figure 37). Peak fall migratory period, measured as the 7-day period with highest bat activity during the fall season, began on 01 August in 2007, although bat activity was steady on either side of this peak period.

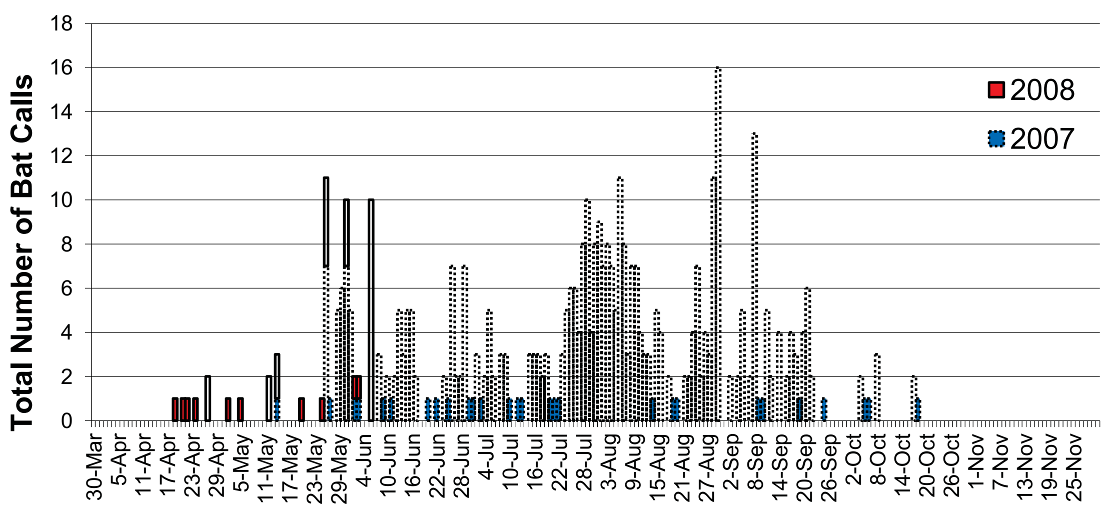


Figure 37. Temporal Distribution in Bat Activity at the Porter MID Microphone

8.5 Porter Site - High Microphone

During the period from 10 May through 15 December, 2007, a total of 35,372 files were recorded and analyzed. During the period from 30 March through 09 June, 2008, a total of 38,784 files were recorded and analyzed. It was determined that 1-and-4 files were of bat origin in 2007 and 2008, respectively. Only a single species was detected across both years; the hoary bat (*L. cinereus*). The timing of bat activity at the Porter HIGH microphone too sporadic to make any substantive observations. The only bat heard in 2007 was detected in late June. All four bat calls heard in 2008 were across two consecutive evenings in early June (Figure 38).

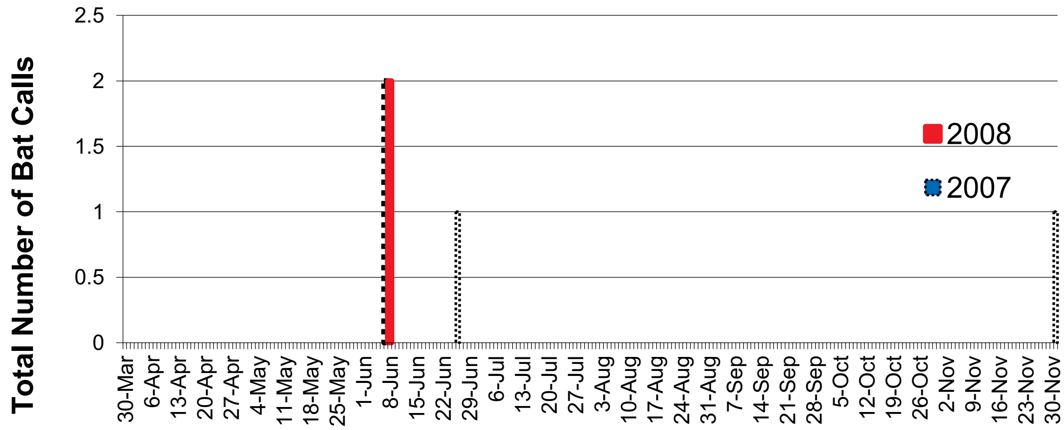


Figure 38. Temporal Distribution in Bat Activity at the Porter HIGH Microphone

9.0 INFLUENCE OF WEATHER ON BAT ACTIVITY

To assess the impact of meteorological conditions on bat activity, we used data collected by the National Weather Service at the Watertown International Airport approximately 30 miles northwest of the project site. We calculated the hourly and nightly values for each variable that we were able to collect (Table 7).

Table 7. Weather variables used in the analysis of bat activity patterns

Weather Variable	Variable Description
Hourly Mean Wind Speed	Mean wind speed averaged over one hour (mph)
Nightly Mean Wind Speed	Mean wind speed averaged over the entire evening (sunset - sunrise) sampling period (mph)
Relative Wind Strength	The percent of the evening sampling period with less than 6-mph winds
Hourly Mean Wind Direction	Mean wind direction averaged over one hour (degrees azimuth)
Nightly Mean Wind Direction	Mean wind direction over the entire evening (sunset - sunrise) sampling (degrees azimuth)
Hourly Ambient Temperature	Average ambient temperature over one hour (°C)
Nightly Ambient Temperature	Average ambient temperature over the entire evening (sunset - sunrise) sampling (°C)
Hourly Total Precipitation	Total accumulation of precipitation over one hour (inches)
Nightly Total Precipitation	Total accumulation of precipitation over the entire evening (sunset - sunrise) sampling (inches)
Hourly Barometric Pressure	Average barometric pressure over one hour (mm Hg)
Nightly Barometric Pressure	Average barometric pressure over the entire evening (sunset - sunrise) sampling (mm Hg)
Hourly Relative Humidity	Average relative humidity over one hour (% RH)
Nightly Relative Humidity	Average relative humidity over the entire evening (sunset - sunrise) sampling (% RH)
Hourly Cloud Ceiling Height	Average cloud ceiling height over one hour (ft)
Nightly Cloud Ceiling Height	Average cloud ceiling height over the entire evening (sunset - sunrise) sampling (ft)
Hourly Visibility	Average visibility over one hour (miles)
Nightly Visibility	Average visibility over the entire evening (sunset - sunrise) sampling (miles)
Moon Cycle	The number of days to the nearest full moon

Our first goal was to find the meteorological variables that would be the most biologically relevant to migratory bats. Assuming bats are influenced by wind conditions, we were looking for the measure of wind speed and wind direction that most closely tracked the decision-making process of bats. We felt that one potentially useful measure of wind speed would be to limit the analysis to the nightly migratory period. For these analyses, we looked at nightly mean wind speed, defined as the mean wind speed from sunset to sunrise. We determined that nightly mean wind speed was highly correlated with daily mean wind speed ($r^2 = 0.768$: Figure 39).

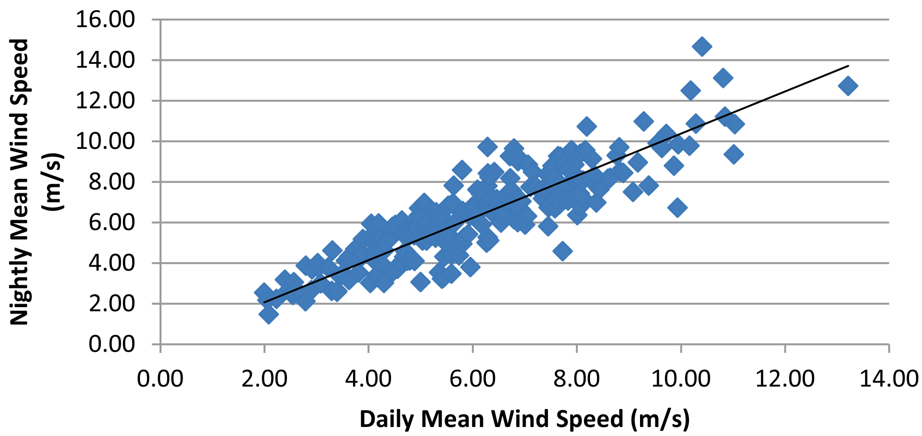


Figure 39. Correlation between Daily Wind Speed and Nightly Wind Speed

Similarly, we found that mean nightly wind direction was highly correlated with mean daily wind direction ($r^2 = 0.815$). Because these variables were highly correlated and nightly mean wind speed most directly measured the conditions under which the bat activity was monitored, we used this variable for all subsequent analyses.

9.1 Exploratory Analysis of the Data

Univariate analysis of the meteorological data suggested several of the predictor variables had no influence on bat activity, including barometric pressure and moon cycle (Figure 40). Similarly, no pattern was seen for wind direction, cloud cover, cloud ceiling height, or nightly visibility. Univariate analysis revealed strong heteroskedasticity and non-linearity between bat activity and the several of the environmental predictor variables (e.g. ambient temperature and wind speed, Figure 41). Bat activity showed a similar relationship with relative humidity in a pattern that was virtually identical to ambient temperature, whereas hourly precipitation showed a non-linearity similar that suggests the majority of bat activity occurred when it was not raining.

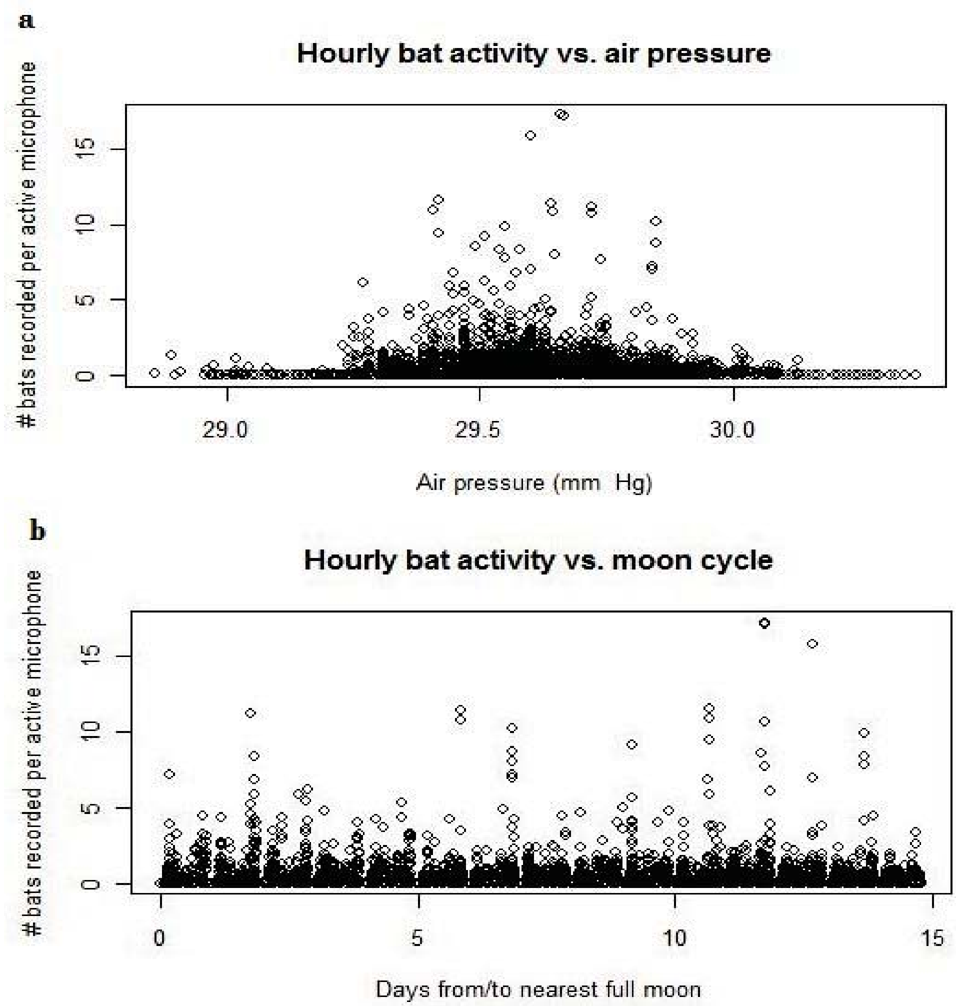
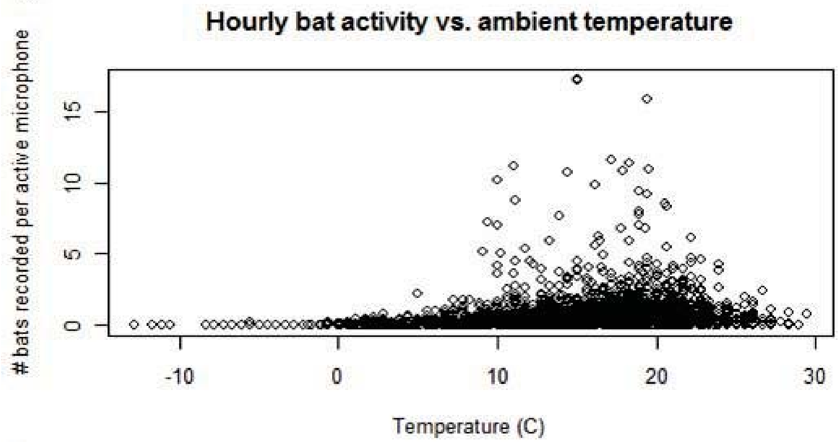


Figure 40. Interaction between hourly bat activity and (a) barometric pressure and (b) moon cycle.

Exploratory analysis of the data revealed a high number of low activity nights that created a non-normal data distribution; this was particularly true for the hourly data summaries (relative to the nightly data summary). For this reason, we relied on non-parametric techniques (classification tree analysis) and nightly bat activity to explore the predictor variables.

a



b

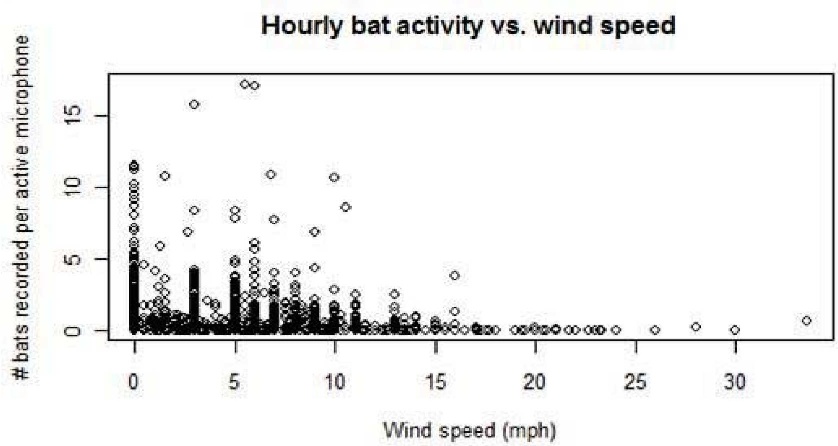


Figure 41. Interaction between hourly bat activity and (a) ambient temperature and (b) wind speed

9.2 Regression Tree Analysis

After conducting the exploratory analyses, we used a regression tree analysis that was limited to those predictor variables that had a substantial impact on bat activity as determined by the random forest analysis (top four predictor variables were selected for inclusion in the regression tree analyses). The most predictive variable (as measured by node priority and node length) was ambient temperature, with nightly bat activity tripling when the mean nightly air temperature was above 13.4°C. Bat activity increased an additional 168% (10.2 calls/night) when air temperature was at least 17.6°C. The highest level of bat activity (12.9 calls/night) was observed when the air temperature was above 17.6°C and wind speed was below 5.5 mph (2.3 m/s: Figure 42). Looking only at the microphones sampling within the rotor swept area (HIGH microphones), air temperature continues to be the most powerful driver variable, but both wind speed and relative humidity influence bat activity; for example, under similar air temperature and wind speed conditions, bat activity rose from 4.98 calls/night to 11.27 calls/night when relative humidity exceeded 89.8%.

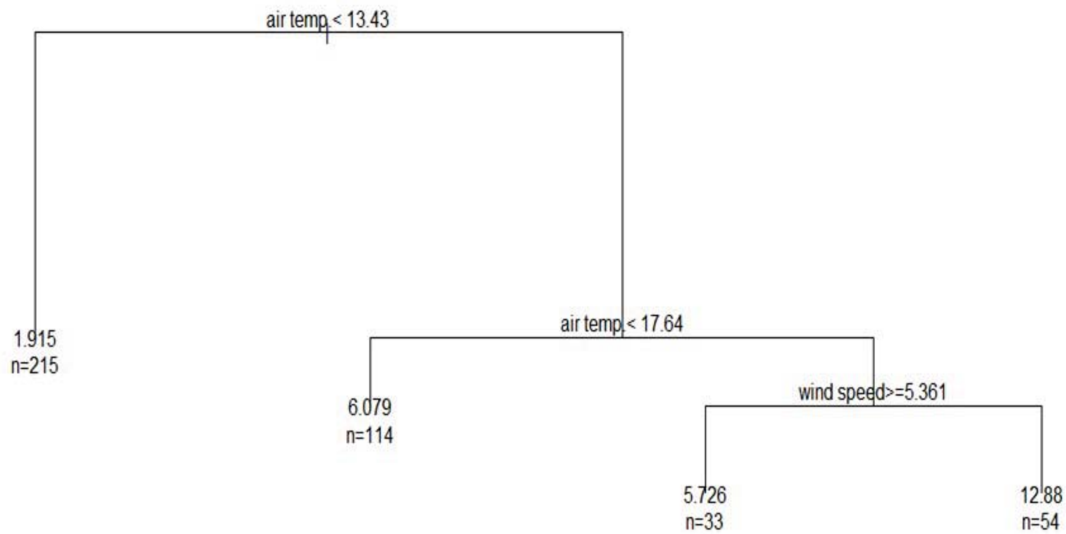


Figure 42. Regression tree for nightly bat activity. The numbers at the terminal nodes represent mean nightly bat activity (n=number of nights).

Next, we limited our analysis to look at just hoary bat activity due to the fact that this species is the most frequently killed bat at wind development sites. This analysis suggests that the strongest predictor of hoary bat activity is time of year, with the fall sampling period having almost four times the average bat activity as other times of the year (Figure 43). Within the fall sampling period, hoary bat activity increased 220% when the nightly ambient temperature was above 14.9°C and increased an additional 178% when the relative humidity was at least 92%.

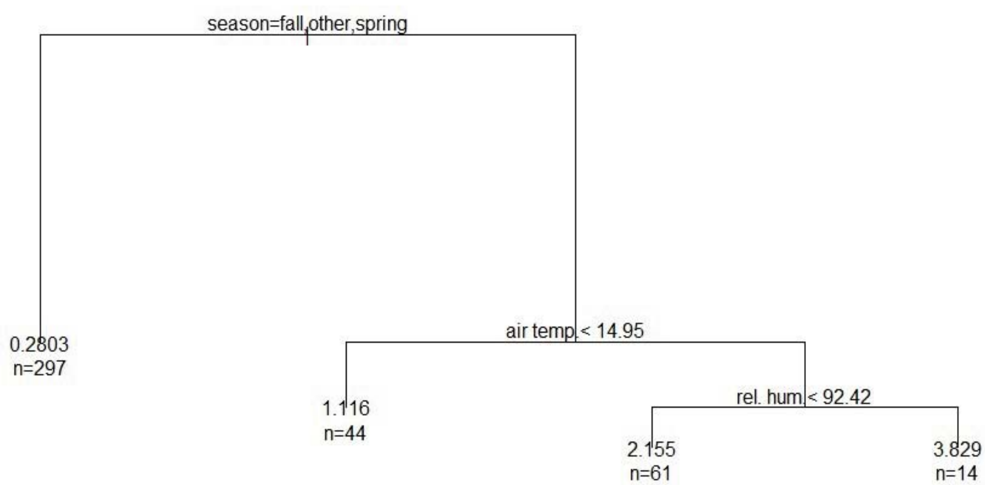


Figure 43. Regression tree for total nightly bat activity in the hoary bat (*L. cinereus*). The numbers at the terminal nodes represent mean nightly bat activity (n=number of nights).

For *Myotis spp.*, bat activity was significantly less influenced by meteorological variables. *Myotis spp*. activity increased five times higher in summer than in the fall sampling period (1.99 calls/night vs 0.38 calls/night) and increased an additional 200% when wind speeds were less than 6.0 mph (2.5 m/s: Figure 44).

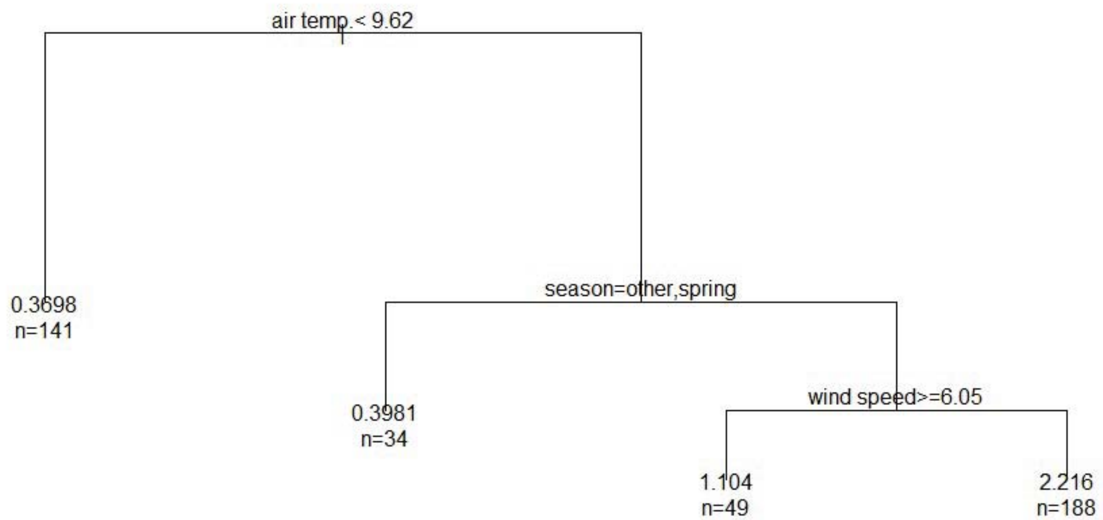


Figure 44. Regression tree for total nightly bat activity in Myotis bats (*Myotis spp.*). The numbers at the terminal nodes represent mean nightly bat activity (n=number of nights).

9.3 General Linear Models

Once we had completed all the exploratory data analysis, we constructed predictive equations using general linear models that incorporated only those variables that appeared relevant based on univariate analyses and the random forest modeling. Nightly ambient temperature (NAT), wind speed (NMWS), and relative humidity (NRH) all contributed to the final model of total nightly bat activity ($F_{6,409}$=28.93, p<0.001, adj. R^2 = 0.288). The same three variables were the only significant contributors for total bat activity within the rotor swept area ($F_{6,409}$=24.85, p<0.001, adj. R^2 = 0.256). For hoary bats, ambient temperature, wind speed, and season (highest activity in summer) were the only three predictor variables that contributed significantly to the model ($F_{6,409}$=11.44.17, p<0.001, adj. R^2 = 0.384). Lastly, for Myotis bat activity, it was ambient temperature, season, and relative humidity that contributed to the model ($F_{6,409}$=11.44.17, p<0.001, adj. R^2 = 0.127).

Table 8. General Linear Models for Night-Averaged Bat Activity

Overall Bat Activity = -7.22050 + 0.4798 (NAT) - 0.3032 (NMWS) + 0.091 (NRH)
Rotor Area Bat Activity = -3.0192 + 0.2145 (NAT) - 0.1314 (NMWS) + 0.0374(NRH)
Hoary Bat Activity = -0.8842 + 0.0618 (NAT) - 0.0357 (NMWS) + 1.3375(MNSUM)
Myotis Bat Activity = -1.9362 + 0.1345 (NAT) - 0.6697 (MNSUM) + 0.0283 (NRH)

10.0 SELF-STANDING PLATFORM MONITORING

As part of an experiment on alternative monitoring methods, NEES deployed a customized tethered blimp at the Maple Ridge project site to determine whether portable high-altitude sampling platforms could provide valuable information under conditions where other monitoring platforms were either inadequate or unavailable.

10.1 Blimp Design

NEES designed and maintains three customized 5.5 m long (12.2 m^3 volume) tethered blimp for use on wind development sites that lack appropriate monitoring platforms (such as a meteorological tower). The blimps are tethered to the ground using a series of support ropes and a central cable attached to a power winch. The winch cable is calibrated for length so that NEES can adjust the height of deployment. NEES suspended an Anabat acoustic monitor and an emergency flash beacon 1.0 m below the center mass of the dirigible to document bat activity and provide visual reference from the ground. The equipment basket is designed on a pivot so that microphone orientation could be controlled independently of the orientation of the blimp.

Figure 45. Deployment of Tethered Blimp at Maple Ridge Wind Farm

10.2 Blimp Deployment

The tethered blimp was set up in the field adjacent to the Cobb Road Tower site on 23 August, 2008. The blimp was tethered to the ground and inflated on-site. The blimp began its ascent at 21:00 and was raised to 76.9 m (250') with the acoustic monitoring facing due north. The blimp was left on-site throughout the evening, recalled, and broken down at 06:00 the following morning.

10.3 Results of the Dirigible Study

During the time of deployment, wind at the sampling site was predominantly from the SSW (220°) at 9.8 m/s (range 7.2 - 11.7 m/s). The blimp withstood the winds without damage and appeared to provide a stable and reliable monitoring platform throughout the evening. The blimp recorded 152 files over the 10 hour sampling period (Figure 46). Only ten files contained bat calls; seven of these calls were from hoary bats (*L. cinereus*) and two were from red bats (*L. borealis*). This generates a detection rate of 9.0 calls/dn; although preliminary in scope, the dirigible had a detection level that was more than four times higher than the overall detection level of bats at the turbine height detectors positioned on the met towers (2.0 calls/dn). Given that the dirigible was sampling at the same altitude and on the same night as the met-tower microphones, it is unclear why the dirigible had higher levels of bat activity. The fact that four of the calls occurred within a four minute period suggests that some of the activity was the result of investigatory behavior by the bats as they crossed the landscape and discovered this novel acoustical signature; it is likely that these four calls were all from the same hoary bat. Nevertheless, the remaining five calls were from two species and were separated by at least 15 minutes and therefore it is unlikely that they represent the same individual.

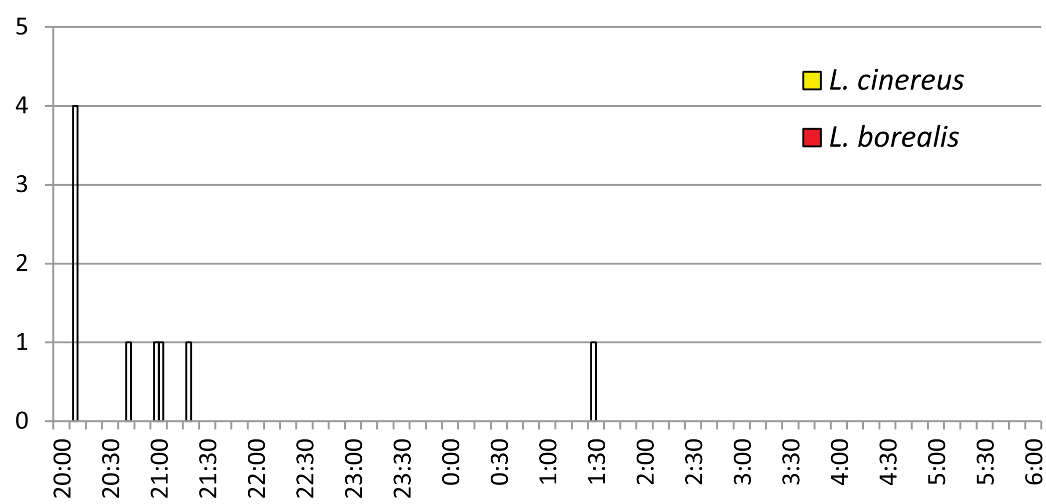


Figure 46. Temporal Distribution in Bat Activity from the Tethered Dirigible

Although these data were preliminary in nature, it is clear that tethered dirigibles offer a potential sampling platform that could be used in situations where meteorological towers can't be deployed. Previous research using blimps and balloons has also suggested that high altitude bat activity is generally underestimated (Fenton and Griffin, 1997; Bach and Rahmel, 2006). Data collected by NEES off the coast of New Jersey suggest tethered dirigibles make an ideal sampling platform for off-shore monitoring for bat activity as well.

11.0 DISCUSSION OF RESULTS

Wind energy has been the fastest growing form of renewable energy in the world for the last two decades (McLeish, 2002; Martinot, 2008), and the United States is considered to have the greatest opportunity for continued growth for wind energy both in the short-term and long-term markets (de Vries, 2008). Although wind energy has many positive attributes, including zero carbon emissions, wide geographic potential, and multiple land use opportunities, wind energy can still have a substantial impact on wildlife, including the destruction of foraging and roosting habitat, alteration of foraging and migratory behavior due to noise or light avoidance, and collision with the wind turbines or met towers (Rodrigues et al., 2006). The wind industry has been attempting to understand and predict these impacts, but often the impact studies are not done, are inadequate, or too poorly designed to allow conclusions about the threat that wind power poses to wildlife (GAO, 2005).

Although the majority of states in the USA have wind profiles that support commercial wind development (GAO, 2005), and more than 20 states have renewable energy requirements (Eckhart, 2006), most states have not taken the effort to develop monitoring requirements that would allow state biologists to adequately assess the impact of wind development on wildlife. New York is ranked 15th in the country for potential wind resources (Pasqualetti, 2004) and was one of the first states to develop monitoring requirements, both before the wind turbines are installed, as well as upon initial operation of the wind project (GAO, 2005). Part of this leadership came from the fact that the Maple Ridge Wind Project was one of the first large-scale (> 200 MW capacity) commercial wind projects developed in the last decade (REW, 2005).

The post-construction wildlife monitoring program at the Maple Ridge Wind project is one of the most extensive investigations on the impact of wind development at any site in the world. NYSERDA realized at the onset of this project that it would be important to analyze the influence of environmental variables on bat activity, and the value of this analysis has been supported by experts in the field (Kunz et al, 2007). Although successful monitoring programs such as this provide information that has direct relevance and use, often too much emphasis goes into data collection and not enough on data management and use (Sauer and Knutson, 2008). The 'grand challenge' is to develop creative solutions that produce a win-win scenario where the wind industry realizes predictable and responsible growth while providing data that allow scientists to minimize the impact of this development on wildlife (Kunz et al., 2007).

To improve the utility of data collected at wind development sites, more effort needs to be made to standardize the sampling methodology so that data collected at different project sites by different consultants are comparable. Although many states have made progress on requiring standardized sampling heights, orientations, and time periods, there has been little effort to determine the impact of the equipment or data analysis methodology on the overall bat activity indices. There has been some small-scale research on the impact of different equipment technology on bat activity estimates (Weller et al., 2007; Allen et al., 2011), however these comparisons are generally limited in scope and have not been applied to the sampling environment of a wind project site. In addition to variation between equipment manufacturers, there has been little effort to standardize methods of calibrating the equipment and documenting both their functional range and functionality. Despite the obvious importance of having equipment that is well-maintained and functioning properly, there is virtually no mention of how consultants should maintain equipment or document their functionality. Similarly, very little has been done to document the impact of various data analysis methods (such as computer-based species filtering and subjective analysis using dichotomous keys) on the overall bat activity measured at a project site.

11.1 The Maple Ridge Data in the Context of Other Wind Development Site

Seasonal bat activity at the Maple Ridge project site was consistent between the two sample years and consistent with bat activity patterns at other wind project sites that have conducted full-year monitoring. Specifically, bat activity was sporadic in early April, became low but sustained through May, and began increasing from June through early August when activity levels generally peaked. This pattern is consistent with our understanding of the phenology of hibernating bats returning from hibernacula in the spring and increasing foraging activity as the summer progresses. The peak in bat activity in early August was generally the result of ground-level increases in foraging and not high-altitude migratory activity. Bat activity within the rotor-swept zone (HIGH microphones) generally peaked in late August and early September, consistent with the general pattern of bat mortality seen at post-construction wildlife surveys (Johnson et al., 2000; Young et al., 2003; Kerlinger and Kerns, 2004; Fiedler et al., 2007; NJ Audubon, 2008; Young et al., 2009).

Nightly analysis of the bat activity data suggests that the 14 hour sampling protocol (18:00 - 08:00) captures the vast majority of bat activity throughout their active season. Across the entire sampling period, there was very little bat activity before 20:00; 97% of this early activity occurred in the fall (September through November), with the remaining 3% occurring during the spring (early June). This early activity is consistent with the migratory behavior of hoary bats (Dalquest, 1943). All the pre-sunset bat activity (n=9 in 2007 and n=1 in 2008) occurred during the spring migration period. Of this pre-sunset bat activity, 70% occurred more than 30 minutes before sunset. These data suggest that the use of absolute time windows may be a better protocol than using relative sunset time because it generates equal sampling effort across the year and captures more of the bat activity than the sunset protocol; this is particularly true for the spring migratory season.

We found significant differences in the level of bat activity between the four sampling locations. Although few sites have as many sampling points at the Maple Ridge project site, these data are consistent with the high level of inter-site variation seen at other wind projects in New York (Reynolds, 2009a; Reynolds, 2009b) and Pennsylvania (Reynolds, 2007). Other projects in Pennsylvania (Arnett et al., 2006; Reynolds, 2008a), Virginia (NEES, 2006), West Virginia (Young et al., 2009), and Wisconsin (Redell et al., 2006) have found inter-site variation in bat activity to be a relatively minor. Although high inter-site variation could lead to large differences in the estimate of total bat activity at a project site, we found that the pattern of bat activity at Maple Ridge (species composition, temporal pattern, and altitudinal pattern) did not differ between the sites. Therefore, requiring additional sampling sites at a wind development site may create more accurate estimates of total bat activity at a wind development site, but it is less likely to provide a qualitatively different description of the bat community. In combination with the lack of annual variation in bat activity, these data suggest that one year of pre-construction acoustic monitoring that relies on multiple sampling locations will provide more information about bat activity than multiple years of pre-construction acoustic monitoring using a single sampling location.

The most significant source of sampling variation in these data relate to the impact of sampling height on bat activity. Consistent with most other monitoring surveys, we found that the ground-level microphones had significantly higher indices of bat activity across the sampling period than microphones placed at turbine height (Fiedler, 2004; NEES, 2006; Reynolds, 2009a). We also found that the species composition of the bat activity varied across sampling height, with *Myotis spp*. being most abundant at the ground-level microphones and hoary and red bats more common at higher altitude microphones; this is similar to many other studies that have used vertical acoustic arrays (Hayes and Gruver, 2000; Arnett et al., 2006; Reynolds, 2008b; Reynolds, 2009a, Reynolds, 2011a). Although ground-level microphones provide the highest estimates of bat activity and may be useful in characterizing how the local population of bats utilizes the landscape, there is no evidence that ground-level monitoring is useful for predicting the subsequent mortality of migratory bats at a wind project. Hopefully, analysis of turbine-level activity indices will prove useful in identifying the seasonal and environmental conditions that stimulate migratory behavior; identification of when bats are moving across the landscape continues to be the best chance of mitigating the impact of wind development on migratory bat species.

11.2 The Influence of Environmental Conditions on Bat Activity

Similar to research conducted at the Maple Ridge project site during the pre-construction phase (Reynolds, 2006), we found that most of the migratory bat activity occurred at lower wind speeds. For the post-construction data, the threshold wind value (based on regression tree analysis) was 5.4 mph (2.4 m/s), slightly higher than the value calculated during the pre-construction analysis (1.3 m/s: Reynolds, 2006). These data are consistent with research conducted at other wind projects in the eastern United States (Arnett et al., 2006) and Europe (Ahlen et al., 2007). Given that bat flights speeds are the same order of magnitude as general wind speeds, the impact of migrating under appropriate wind conditions is critical (Hedenstrom, 2009). Because research in Alberta Canada (Baerwald et al., 2009) and Pennsylvania (Arnett et al., 2010) have shown the effectiveness of curtailing wind turbines at low wind speeds, it is important to identify the conditions when feathering of the turbines will have the greatest reduction in bat mortality.

The most consistent environmental predictor variable with ambient temperature, with all models suggesting bat activity increases with increasing nightly mean temperature. For all bats, we found a four-fold increase in nightly bat activity when the air temperature was above 13.4°C. For hoary bats during the fall migratory period, the models suggest that bat activity doubles when air temperatures are above 15°C. Similarly, Arnett et al. (2005) found that hoary bat activity increased when ambient temperatures were above 12°C. For several of the models, relative humidity also influenced the level of bat activity; although the impact was statistically significant, the impact was relatively small. The greatest influence was for migrating hoary bats, where migratory activity increased 177% when the relative humidity was above 92.4%. It is possible that this increase in bat activity may coincide with the high humidity conditions that occur when cold fronts move across the landscape. Because cold fronts in the northern hemisphere generally produce winds from the north or northwest (UIUC, 2010), passage of a cold front may provide favorable wind conditions for the fall migration. This is consistent with patterns of bird migration (Able, 1973; Bruderer, 1997) and mortality (Brewer and Ellis, 1958) in the northeast. In September 1949, Carter (1950) documented approximately 200 red bats migrating in a northwesterly wind off the coast of the Atlantic during light rain, conditions consistent with the passage of a cold front. Constantine (1959) documented hoary bats flying on the leading edge of a moving fog front on two separate occasions, observations consistent with bats moving during or soon after the passage of a cold front.

The reliance on predictable wind patterns, such as the passage of a cold front, would be an effective way of orienting migratory behavior and would eliminate the need for a precise compass sense or other navigational aid (Waterman, 1989). This may be particularly important for bats, which generally rely on short-range acoustics to navigate under non-migratory conditions. If bats are using cold fronts to time their migration, it is unclear why barometric pressure was not a significant predictor variable in any of the models, especially given that bats are the only mammal with a Vitali organ that can sense changes in air pressure (Paige, 1995). Cryan and Brown (2007) found that low barometric pressure was predictive of migratory bat activity off the coast of California, but no such pattern was observed at the Maple Ridge project site. It may be because the bats rely on changes in pressure rather than absolute pressure to time their migration.

Post-construction monitoring at wind project sites have made it obvious that bats and birds have different migratory phenologies that most likely relate to differences in their physiology and ecology. Regardless of the details of the migratory event, bats and birds both need to accomplish the similar tasks and likely rely on similar intrinsic (endogenous schedule and fat reserves) and extrinsic (location of stopover point and weather conditions) cues (Liechti and Bruderer, 1998). This is likely why there are many observations of bats and birds migrating together (Hill and Smith, 1992). Both groups of animals appear to reduce migratory activity when it is raining (Schaub et al., 2004). In contrast to birds, however, bats do not appear to be inhibited by increasing cloud cover (Alerstam, 1978) or confused by artificial light sources (Waterman, 1989) as much as birds.

In many respects, the data collected as part of this NYSERDA research effort are consistent with data collected at many other wind project sites. These results highlight some of the temporal, spatial, and environmental components of bat activity that may play an important role in predicting the impact of wind development on bat populations at future wind development sites. However, the most significant and cautionary findings are the strong interaction effects observed between these variables. These strong interactions, particularly the impact of species and season on bat activity, suggest that separate analyses of summer foraging (primarily of *Myotis spp*. and big brown bats (*Lnoct-Efusc*) and migratory behavior (primarily of hoary bats and red bats) may provide a clearer picture of a projects' potential impact.

11.3 Potential Monitoring Methods to Estimate Risk

The large potential impact of wind development on bats, first realized following construction of the Mountaineer Wind Energy Center in West Virginia (Kerlinger and Kerns, 2004), has spurred the implementation of a variety of monitoring methods to estimate the mortality risk to bats. Although the need to define acceptable survey technologies and to develop consistent and scientifically rigorous protocols has been identified as a research goal since bat mortality was first documented (Energetics, 2004), very little independent research has been conducted to meet this goal. In the absence of consensus on the best survey technologies, pre-construction monitoring has been conducted at most wind development sites using a variety of research techniques such as mist-net surveys, radar analysis, ceilometry, infra-red monitoring, and acoustic monitoring.

Ceilometry was the first method used to monitor nocturnal migratory activity, although it was originally only applied to migratory birds (Liechti et al., 1995). More recently, ceilometry has been used at several wind development sites (Plissner et al., 2006), including the Maple Ridge project site, to document bat activity. During the pre-construction phase of the Maple Ridge project, ABR, Inc. documented 179 bats flying near a met tower using a hand-held spotlight with a red filter lens (Mabee et al., 2004). Similar methods were employed at a wind project in West Virginia, but the researchers were less confident about distinguishing between bat and bird silhouettes and noted that most of the observable bat activity occurred within 8-m of the ground (Roy et al., 2005). Ceilometry is a useful technique to observe bat foraging behavior and to document how bats react to the guy wires of the met tower. Still, it is uncertain that ceilometry can be used to characterize bat activity near the rotor swept area of the turbines, nor is it clear that these data can be expanded to represent bat activity across the entire project area.

Radar has been used to document the passage rate of night migrants birds for decades and was a major component of the pre-construction wildlife monitoring at the Maple Ridge project site. Radar surveys were conducted for 60 nights at two locations during peak fall migration using an X-band system in both the horizontal and vertical plane (Mabee et al., 2004). This study helped identify that most of the migratory activity across the project site occurs in a southerly direction and that the target density within the rotor swept area was 11 targets/km/hr; however, this study could not reliably distinguish between migratory bird and bat activity (Mabee et al., 2004). The consensus of radar experts is that any criteria used to distinguish bats and birds (i.e. air speed or flight pattern) is subjective and lacks field validation (Ron P. Larkin, University of Illinois, Champaign-Urbana, unpublished). Therefore, when radar surveys are done, they should be conducted simultaneously with acoustic monitoring to separate bat activity from bird activity (OMNR, 2007) within the shared detection range.

Mist-netting is the only reliable monitoring methodology to document the presence of an endangered species. In conjunction with radiotelemetry or light-tagging, mist-netting is also an effective way to look at foraging activity and habitat utilization within a project site. Nevertheless, most bat experts agree that mist-netting is not an effective method for assessing potential risk to bats at a proposed wind energy site (CEC, 2007). Consequently, most state agencies only recommend mist-netting when a project has the potential to impact rare or threatened species.

Due to its taxon specificity and cost-effectiveness, acoustic monitoring has become the most commonly employed pre-construction monitoring technique for the wind power industry. Consequently, many state wildlife agencies are now creating acoustic monitoring protocols that have the potential to improve the quality and comparability of pre-construction monitoring data.

11.4 The Value of Pre-Construction Risk Assessments

The goal of a pre-construction risk assessment is to determine the extent to which a proposed project area is used by migrating, breeding, and wintering bats, and how the physical and biological features of the project site may influence such use (NYDEC, 2009). Although state requirements may differ, some level of pre-construction risk assessments are generally required in order to estimate the impact of project development and to help avoid or minimize impacts to wildlife and their habitats following construction of the project (USFWS, 2010). In the absence of concern for state- or federally-endangered species, some states do not require any site-specific data to be collected as part of their bat risk assessment. Other states, including New York, require some level of habitat assessment for each project site and, if there is concern about endangered species, may require summer mist-netting surveys. This was the case for the Maple Ridge wind project site, given a large hibernaculum containing the federally-endangered Indiana myotis (*Myotis sodalis*) was only 19 miles northwest of the project area and the site assessment documented the presence of potential foraging and roosting habitat of the Indiana myotis. After an extensive mist-netting study that sampled the potential roosting habitat during the breeding season, it was concluded that the Maple Ridge project site would not impact the summer or winter populations of this species (Reynolds, 2004). The Maple Ridge project site was also the first wind development site to use ceilometry to estimate bat migratory activity (Mabee et al., 2004).

To determine the impact of wind project development on migrating bats requires a completely different set of research tools, and in the absence of general migratory patterns, requires the collection of site-specific data. Prior to the Mountaineer study in West Virginia, scientists lacked the technology and protocols to collect data on the migratory activity of bats. In the subsequent years, scientists and consultants have developed or improved upon a variety of techniques to sample bat migratory activity; the greatest improvement in pre-construction monitoring is the ability to monitor bat migratory activity at high altitude (> 30m above ground) using platform-based acoustic monitors. This was a technique pioneered by North East Ecological Services and the Maple Ridge project site was one of the first wind development sites to use met-tower based microphones (Reynolds, 2006). Although the construction schedule prevented sampling during the fall migratory period, we were able to monitor the spring migratory period. This study showed the potential for acoustic monitoring to predict migratory bat activity and it was the first study to suggest that bat migratory activity was highly episodic and that most of this activity occurred during low wind speed conditions (specifically below 1.3 m/s: Reynolds, 2006).

11.5 Acoustic Monitoring to Evaluate Bat Mortality Risk

There is solid evidence that post-construction acoustic monitoring surveys are strongly correlated with post-construction carcass surveys when they are done simultaneously, despite diverse methodologies (Kunz et al., 2007; Baerwald, 2008). Although this is outside the scope of the current report, this correlation is the focus of an ongoing NYSERDA project. It is also clear that Anabat detection systems are the dominant monitoring system utilized to date and that zero-crossing analysis provides sufficient information to recognize acoustically distinct species (Kunz et al., 2007). Therefore, monitoring technology is beyond the scope of this report but needs to be considered when attempting to compare activity indices from different project sites. It is also clear that ground-based acoustic monitoring does not adequately predict bat mortality (Jain, 2005; Young et al., 2009); this is presumably because ground-based monitoring does not reflect bat activity within the rotor-swept area where bats are colliding with the turbines. However, it remains unproven that pre-construction monitoring can accurately predict post-construction bat fatalities. Given the general lack of adequate Before-After Control-Impact (BACI) studies and the failure to address some basic assumptions of acoustic monitoring (see Section 11.0), this lack of correlation is not surprising. Since any correlation would be difficult to detect given the inherent variability in the data, the solution is not to abandon pre-construction monitoring but to improve study protocols to account for the variation (Arnett, 2007).

11.6 Best Practices for Monitoring Migratory Bat Activity

Assuming that acoustic monitoring can predict bat mortality, study protocols need to be developed to create consistent and comparable data sets that accurately characterize bat activity across a project site. As one of the first states to develop a pre-construction monitoring protocol, the NYDEC has taken a lead role nationally in developing standardized protocols (NYDEC, 2009). Although the NYDEC was one of the first states to provide specific monitoring protocols, most of the protocols were developed through expert opinion consensus and not through controlled experiments. Therefore, it is important to continue validating these protocols to ensure that they represent best practices. One of the most important requirements is that acoustic detectors be placed "as high in altitude as possible or at least 150 feet above the ground surface" (NYDEC, 2009). This is critical for sampling within the rotor-swept air of the turbine and has been incorporated into many other state protocols, including Arizona (AGFD, 2009), California (CEC, 2007), Maine (Jones, 2006), New Jersey (NJDEP, 2010); Pennsylvania (PACG, 2007), and Vermont (VTANR, 2006). Elevated sampling using met towers is also consistent with all the available expert recommendations (Kunz et al., 2007; Hein et al., 2011). Although the NYDEC does recommend ground-based acoustic monitoring to supplement the high altitude monitoring, these data should only be interpreted in the context of foraging activity or habitat usage, not migratory behavior (Kunz et al., 2007).

The NYDEC recommends recording from 0.5 hrs prior to sunset until 0.5 hrs after sunrise between April 15 and October 15. Data collected from Maple Ridge and other wind development sites throughout the northeast suggest that this temporal and seasonal window captures the vast majority of bat activity during the active season (see Figures 2-5). The NYDEC also recommends that the microphones “be oriented in the likely direction of arriving migrants (south in the spring, north in the fall)”, and this was the orientation used during this study. Other studies have varied the orientation of the microphones to sample topographic (e.g. ridge lines) or habitat (e.g. forest or water edge, features that may influence migratory bat activity (Hein et al., 2011). A pre-construction monitoring survey in coastal New Jersey used three microphones mounted in different orientations (at roughly 10m altitude) and found that northern and western microphones detected similar levels of bat activity during the fall migratory period, with the eastern microphone detecting 77% less bat activity (Reynolds, 2011b). In contrast, acoustic monitoring at five met towers at the Hoosac wind facility in Massachusetts used variable microphone orientations and found that location (tower) only explained 2% - 8% of the variation in bat activity (Hein et al., 2011). Although fixed orientation has the advantage of comparability between studies, there is also conservation management value in orienting microphones to maximize the level of detectable bat activity (Weller and Zabel, 2002). Regardless of which approach is used (variable orientation and fixed orientation), there are no studies that compare the impact of microphone orientation on bat activity estimates.

Lastly, the draft NYDEC guidelines in 2007 recommended the use of a vertically-oriented microphone at the top of the met tower. Although no justification is provided for this approach, the assumption is presumably that vertically-oriented microphones detect bat activity at a higher altitude than would be captured using only horizontal microphones. Data collected at the Noble Ellenburg Windfarm utilized both horizontal and angled (45° from horizontal) microphones on a 2m FAA receiver tower (Reynolds, 2010). This study showed that the horizontal microphone had a 64% higher activity index but that the angled microphone detected more migratory bats (hoary bats and red bats) that were presumably migrating at a higher altitude (Reynolds, 2010). This study suggests that horizontal and angled (vertical sampling may not be practical for long-term monitoring using condenser microphones) detectors are sampling different volumes of air, but to date there has been no study done to compare the impact of a microphone angle on bat activity estimates.

The current NYDEC Guidelines for Conducting Bird and Bat Studies at Commercial Wind Energy Projects (NYDEC, 2009) is designed to generate the best data that can be used to inform the siting of wind development sites in the state of New York. The data collected from the Maple Ridge project site suggest that the NYDEC protocol is well designed and capable of characterizing bat activity. The focus on a single year of pre-construction acoustic monitoring (in contrast to the three year pre-construction recommendation of the U.S. Fish and Wildlife Service (USFWS, 2004) should adequately characterize the seasonal activity at the project site; additional years of pre-construction monitoring are unlikely to provide qualitatively different results. The NYDEC protocol also focuses on ensuring appropriate vertical sampling of a potential wind development site using met towers. Data collected at the Maple Ridge project site confirm that high altitude sampling is the most appropriate method for documenting migratory bat activity. Although the NYDEC protocol does not mention the need for multiple sampling platforms, data collected at Maple Ridge suggest that multiple sampling platforms may produce different measures of bat activity but that each platform produced similar overall patterns. This report offers only three potential modifications to the NYDEC protocol. First, data collected in this study suggest relying on relative sunset time produces unequal sampling effort across the year (as total sampling time varies seasonally) and may miss some of the pre-sunset migratory activity seen in the spring. Although this is unlikely to change the overall measures of bat activity, absolute time measures may be statistically more appropriate and capture more bat activity than sampling protocols relying on relative sunset time. Second, data from the current study suggest that there are strong interactions between sampling variables (particularly between sampling height, season, and species) that may be lost by relying on a single metric of overall bat activity. NEES suggests that bat activity indices be generated for each sampling season (spring, summer, and fall) and for each sampling height. For species with adequate sample sizes, it may also be useful to document both overall activity levels and activity levels at each height or season.

Lastly, the NYDEC does not outline options available to wind developers when a met tower is not available for attaching acoustic monitors. At several project sites with which NEES has been involved, state regulators generally focus on more extensive ground-level monitoring to compensate for the lack of vertical sampling. Data collected for this study suggests that additional ground monitoring will produce valuable data but it will not provide information on migratory bat activity. Given that sampling height was the largest source of variation in the current study, these data are unlikely to be comparable to met tower-based projects due to the fact that ground detectors have higher levels of overall bat activity and are generally different from elevated detectors in both their seasonal variation and species composition. Tethered dirigibles may be a viable alternative that supplements ground monitoring stations with turbine-level monitoring during peak fall migration.

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Andrew M. Cuomo, Governor

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