Research Article

Monitoring the Potential Impact of A Wind Development Site on Bats in the Northeast

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Abstract

Recent observations in the eastern United States suggest that bat communities can be at substantial risk of turbine-related mortality. Given that wind power development is the fastest growing energy sector in the world, there is an immediate need to develop survey protocols that can reliably assess the potential risk of future wind power development on both resident and migratory bat populations. I surveyed the Maple Ridge Wind Project site in New York, USA, during the spring migratory season and summer reproductive season using acoustic monitoring and mist net capture techniques. Bat activity was low across the project site during the summer months. The bats I observed at the site flew near the tree canopy, well below turbine height. Acoustic survey data collected during the spring migratory season suggests migratory behavior is highly episodic, being higher on warmer days with lower wind speeds. Knowledge of the influence of meteorological conditions on bat migration will require data on the spatial and temporal components of this behavior. Although acoustic monitoring using vertical acoustic arrays is currently limited to measuring the risk of bat mortality at wind development sites, it may be a valuable tool to increase our knowledge of the migratory phenology of bats. (JOURNAL OF WILDLIFE MANAGEMENT 70(5):1219–1227; 2006)

Key words

acoustic monitoring, Anabat, migration, Myotis spp.*, New York, Tug Hill Plateau, wind power.*

New York State has an aggressive renewable portfolio standard that dictates 25% of the energy used in the state must be derived from renewable sources by 2012. Wind power is the fastest growing form of renewable energy in the United States (McLeish 2002). Because New York has the highest wind ranking of any state in the Northeast (Pasqualetti 2004), it is believed that a large portion of that renewable energy could be generated with wind power. Although wind power generally is considered an environmentally sustainable method of power generation, the potential mortality risk of wind development on migratory birds has been recognized for decades (Schmidt et al. 2003). Research into the causes and timing of avian mortality has led to the establishment of standard protocols for monitoring resident and migratory bird species that may be impacted by wind turbine projects (Anderson et al. 1999). However, prior to the installation of the Mountaineer Wind Energy Center in the central Appalachians of West Virginia, little attention had been given to bat mortality at wind energy sites. As part of an ongoing avian survey at the Mountaineer site, biologists discovered over 400 dead bats during a short sample period during the 2003 fall migratory season, with total estimates for 2003 in excess of 2,000 bats (Kerlinger and Kerns 2004). A similar pattern of mortality was observed in the 2004 fall migratory season; although the total estimated mortality increased to over 4,000 bats (Arnett 2005). Data from Mountaineer and other wind development sites suggest that bats are at a much higher mortality risk than previously estimated, particularly in the eastern United States (Johnson 2005). In a survey of 9 wind projects across the United States, Johnson (2005) observed that >90% of bat mortality occurred during the fall migratory season (Aug–Oct) and that migratory bats (e.g., hoary bat [*Lasiurus cinereus*], eastern red bat [*Lasiurus borealis*], and silver-haired bat [*Lasionycteris noctivagans*]) accounted for >80% of the total mortalities.

In order to ensure this wind development does not negatively impact bat populations, more effort needs to be made to establish survey protocols that are designed to answer the specific concerns of wind turbines. The Bats and Wind Energy Cooperative (BWEC), founded by the American Wind Energy Association, Bat Conservation International, the National Renewable Energy Laboratory, and the United States Fish and Wildlife Service, was formed specifically to identify research priorities, to establish rigorous survey protocols, and to develop solutions that will reduce the impact of wind development on bats (Bat Conservation International 2004). However, the ability to generate reliable risk assessments is greatly hampered by the lack of baseline data on bat population distributions and densities throughout much of the United States. Furthermore, although many historic and anecdotal accounts of migratory behavior in bats exist (e.g., Saunders 1930, Terres 1956, Gifford and Griffin 1960), there are few studies on the migratory phenology of bats (Hall 1962, Davis and Hitchcock 1965, Tuttle 1976, Barclay 1984, Cryan 2003). Moreover, most of these are limited to the genus *Myotis* rather than the migratory tree-roosting bats, and none of these provide data on their migratory pathways or flight altitude of bats.

There are 9 species of bats with geographic range overlap at this project site in western New York: little brown bat (*Myotis lucifugus*), northern long-eared bat (*M. septentrionalis*), eastern small-footed bat (*M. leibii*), Indiana bat (*M. sodalis*), big brown bat (*Eptesicus fuscus*), eastern pipistrelle bat (*Pipistrellus subflavus*), silver-haired bat, hoary bat, and red bat. Although most bat communities in the Northeast are dominated by *Myotis* bats (Saunders and Barclay 1992, Sasse 1995, Hendricks et al. 2004), the combination of high

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latitude, lake-effect precipitation and wind from Lake Ontario, and the high elevation of the Tug Hill Plateau relative to the surrounding lowlands, may shift the community composition towards species such as the silver-haired bat and hoary bat (Barclay 1985, Ports and Bradley 1996) and preclude species such as the red bat that are typically found in lowland habitats (Carter et al. 2004). Locally, there were likely to be low levels of Indiana bats because of the absence of lowland riparian habitat (U.S. Fish and Wildlife Service 1999), although there is increasing evidence that this species can be found at higher elevations in the central and southern Appalachians (Menzel et al. 2001, Britzke et al. 2003).

My purpose was to investigate spatial and temporal patterns of bat activity across a proposed wind energy project site during the summer breeding season and the migratory season to relate activity to potential bat mortality. A stronger understanding of bat activity levels prior to project construction could assist in turbine placement within the Maple Ridge wind project and help identify potential microhabitat features that would pose a risk of bat mortality at future wind development sites in the East. I specifically aimed to test 3 hypotheses regarding bat activity at the project site: 1) the physiogeography of the site would limit the species diversity and total bat abundance at the project site, 2) the bat community would be shifted towards species that are more commonly found at higher elevation (e.g., hoary bat and silver-haired bat), and 3) the climate of the project site would shift the sex ratio of the bat community towards males that were not as energy limited as reproductive females during the summer months.

Study Area

The Maple Ridge Wind Project (PPM Energy, Portland, Oreg., and Horizon Wind Energy, Houston, Tex.) is a 198 turbine project that began construction in August 2005. The area encompasses approximately 67 km^2 within the Northeastern Highland Ecoregion, or Tug Hill Plateau region, of western New York (Omernik 1987). Vegetation within the study area is Northern Hardwood Forest type (Eyre 1980), although much of the current regional land use is devoted to agricultural crops. The typical frost-free period in the plateau region is 100–120 days (New York State Climate Office 2006). High annual precipitation (110 cm) contributes to the maintenance of a variety of perennial streams that flow off the plateau into the surrounding lowlands (Penn State Earth System Science Center 1998). The Maple Ridge study site has a mean elevation of 545 m above sea level (asl), rising from 300 m asl at the eastern margin up to 600 m asl along the western edge of the plateau. The wind energy project is 32 km southeast of a Priority II hibernaculum for the endangered Indiana bat and wholly within the geographic distribution of the eastern small-footed bat, a New York State Species of Special Concern.

This combination of cropland, lowland forest, mixed hardwood forest, and slow-moving water makes the Tug Hill Plateau, and the adjacent Black River watershed, potential roosting and foraging habitat for most of the bat species found in the Northeast. Research by Fenton and Downes (1981) along the Black River watershed documented 6 species of hibernating bats, including the Indiana bat. Summer research also confirmed the presence of at least one migratory bat species, the hoary bat (B. Fenton, University of Western Ontario, personal communication).

Methods

One of my major goals was to obtain a comprehensive survey of the bat community at the Maple Ridge wind project area.

Summer Survey

Net capture.—Mist net captures are the most definitive method of documenting the presence of a species. I captured bats from 22 June through 5 July 2004 using 38-mm, 50-denier mist nets (Avinet, Inc., Dryden, New York) at 24 sites throughout the project area. I distributed netting sites throughout the project area, and I chose net locations to sample the full variety of available habitats. I used horizontal nets (ranging from 6 to 18 m in length by 2.6 m in height), canopy nets (both 6 and 9 m in height by 3 m in width), and triple stack nets (9 m in length by 7.8 m in height) in a variety of habitats, including across woodland trails, along the edges of water sources (cattle ponds, creeks, and swamps), and along field edges. I opened nets at sunset and monitored them continuously until 0100 hours. I identified captured bats to species and age (adult or juvenile based on epiphyseal–diaphyseal fusion of the metacarpal phalange joint; Anthony 1988), and I assessed reproductive condition (based on Racey 1988). I also collected mensural data, including body size (forearm length in millimeters) and body mass. I marked all bats with numbered (e.g., NYDEC 01XXX) lipped aluminum forearm bands (Porzana, Ltd., East Sussex, United Kingdom) supplied by the New York Department of Conservation.

Acoustic monitoring.—Acoustic monitoring is a passive sampling system that should not influence bat behavior or generate avoidance responses. Acoustic monitoring uses ultrasonic microphones (bat detectors) that are capable of detecting and recording the echolocation calls of bats in flight. The detection range of a typical bat detector (approx. 15–25 m) provides a much larger sampling area than a mist net. However, acoustic monitoring is less resolute to reliably identify species with overlapping acoustic signatures. This is particularly true for bats within the genus *Myotis* (Ahlen 2004, Jones et al. 2004; but see also Britzke et al. 2002).

I conducted acoustic monitoring during the summer of 2004 (23 Jun through 5 Jul). I chose acoustic monitoring sites to sample the full variety of available habitats available within the project area. In the summer sampling period, I monitored 35 sites in the wind project area for a single night from 1900–0700 hours using an Anabat 6.2 detector connected to a CF-ZCAIM data storage unit (Titley Electronics, Ballina, New South Wales, Australia). I mounted each detector microphone on a 1.5-m pole with the microphone facing the ground to prevent condensation

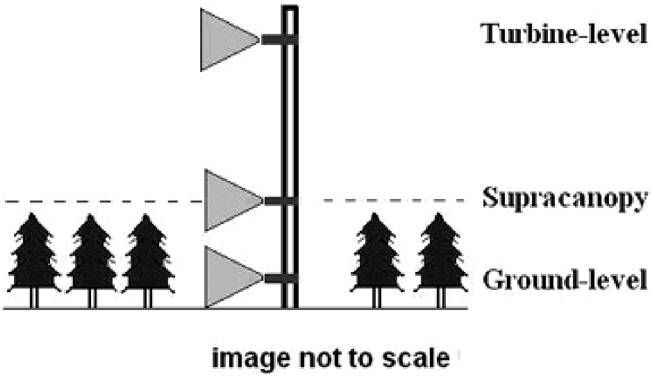

Figure 1. A schematic representation of the vertical acoustic array showing the 3 microphone placements along the meteorological tower, Lewis County, New York, USA, 2004.

from collecting on the microphone screen. Echolocation calls were reflected towards the microphone using a 10 by 10 cm lexan plate mounted at a 45° angle from horizontal. Therefore the sampling space was oriented parallel to the ground. I attached microphones to the detector using a 3-m shielded video cable (Titley Electronics, Ballina, New South Wales, Australia). Each detector and CF-ZCAIM unit was housed in a watertight storage box powered by a 12 V deep cycle battery. The microphones I used were shown to detect the echolocation calls of approaching bats up to 11.6 m away with a potential sampling cone of 254 m^3 (Larson and Hayes 2000). My field testing showed that all microphones detected a repeating ultrasonic signal (Bat Chirp; Reno, Nevada) from >22 m.

I defined a *bat pass* as any sequence >0.5 millisecond duration that had at least 2 separate calls (Thomas 1988, Gannon et al. 2003). I defined a *feeding buzz* as a rapid series of echolocation calls that were characteristic of the attack phase of foraging insectivorous bats (Grindal et al. 1999). I collected data on maximum frequency, minimum frequency, changes in frequency with time, and call duration from each call sequence. I determined species presence by comparing these data with a dichotomous key I developed for species found within the northeastern United States. Due to the qualitative nature of my analysis and the similarity of calls between the *Myotis* species, my classification of these calls was restricted to genus. For similar reasons, I assigned calls that I could not identify confidently to either the big brown bat (*E. fuscus*) or the silver-haired bat (*Lasionycteris noctivagans*) to the Efus-Lnoct group (Betts 1998).

Migratory Activity

Acoustic monitoring.—I conducted acoustic monitoring during the spring 2005 migratory season (10 Apr through 22 Jun) at 2 locations (Kabinski and Porter) in the northern section of the project site. I sampled each site using Anabat 6.2 detectors set up on 2 separate vertical arrays. Each array was located on an existing 50-m meteorological tower that was located within the wind project area (Fig. 1). Each tower was lowered to the ground to mount the acoustic array. Each array consisted of 3 microphones mounted at ground level (roughly 7 m above ground), supracanopy level (roughly 25 m above ground), and turbine level (50 m above ground). I oriented the turbine level microphones southeast into the prevailing wind. I oriented the ground microphone south towards the closest trail or linear landscape element to document the use of these features by commuting bats. I oriented the supracanopy microphones north towards the direction of the nearest known Indiana bat hibernacula located 31 km away in Watertown, New York. I tested each microphone while the meteorological tower was on the ground, to ensure a minimum sampling distance of 20 m.

I attached microphones to the Anabat detector using a shielded video cable with an integrated pre-amplifier. Each detector was connected to a CF-ZCAIM data storage unit. The Anabat detectors and data storage units were housed in NEMA Type-4 steel weatherproof boxes that were mounted to each meteorological tower. Each array was powered by a 12-V power supply attached to a 30-W photovoltaic charging system. Each array was programmed to monitor from 1900 through 0700 hours.

Meteorological data.—Technicians from the Maple Ridge wind development group collected meteorological data using a NRG 200P anemometer and an 110S Temperature Sensor (NRG Systems, Hinesburg, Vermont) mounted on the Porter meteorological tower. They mounted both instruments at 49 m above ground. They collected data on wind speed (m/sec), wind direction, and temperature (°C) every minute and averaged for each 10-minute interval. I then used these data to generate daily averages, daily maximum, and daily minimum values for each measurement. I converted mean daily wind direction into categorical data using 8 compass bearings (N-NE, E-NE, E-SE, S-SE, S-SW, W-SW, W-NW, and N-NW). In addition, I calculated average values for each variable from 1900 through 0700 hours each day to generate nightly average measurements.

Statistical Analyses

To examine temporal patterns of bat activity during the summer sampling periods, I partitioned each night into 3 equal-length periods; early (1900–2259 hours), middle (2300–0259 hours), and late (0300–0700 hours). I categorized sampling sites into 5 habitat types (trails and roads, rivers and creeks, ponds, fields, wetlands and marsh habitat). I examined summer bat activity using a 2-factor (sampling period × habitat type) general linear model with post hoc Tukey's multiple comparisons procedure. To examine temporal patterns of bat activity during the spring migratory sampling period, I partitioned each night into 3 equal-length periods; early (1900–2259 hours), middle (2300–0259 hours), and late (0300–0700 hours). I investigated seasonal variation in bat activity by dividing the sampling period into 3 equal-length intervals; early (10 Apr through 4 May), middle (5 May through 29 May), and late (30 May through 22 Jun). I examined the spring bat activity using a 3-factor (night period × sampling period × sampling height) general linear model with post hoc Tukey's multiple comparisons procedure. The analysis of the impact of

Table 1. The number of bats captured at the Maple Ridge Wind Project site during the summer 2004 breeding season (22 Jun–5 Jul).

Species	Male	Female	Male and nonreproductive female	Pregnant	Lactating	Postlactating
Northern long-eared bat	9	8	10	0	7	0
Little brown bat	15	0	15	0	0	0
Big brown bat	2	1	2	0	1	0
Total	26	9	27	0	8	0

weather conditions on spring migratory bat activity was limited to the 74-day sampling period (10 Apr through 22 Jun) where both activity data and meteorological data were collected. Because of the large number of days with no detectable bat activity (19 nights or 26% of the sampling days), I categorized activity data as none (0 bats/night), low (1–2 bats/night), medium (3–6 bats/night), and high (>6 bats/night). I established these categories post hoc to minimize group size variation. I compared meteorological variables using Pearson correlation analysis to determine the degree of independence. For wind speed and ambient temperature, I analyzed bat activity by multiple comparison analysis using a general linear model with Tukey's multiple comparisons procedure. For the wind direction data, I categorized mean daily azimuth values into 8 45° segments. I analyzed for a nonrandom distribution of bat activity with respect to wind direction using a chi-squared goodness-of-fit test. For all statistical analyses, I used either SAS (SAS Institute, Cary, North Carolina) or Mini-Tab v13 (Minitab Inc., State College, Pennsylvania).

Results

Summer Survey

Net captures.—I conducted mist netting at 24 sites, with a total sampling effort of 130 net-nights. These efforts resulted in the capture of 35 bats of 3 species, with a sitewide capture rate of 0.3 bats/net-night (Table 1). I did not capture any bats at 40% of the sample sites. Across the study area, 74% of the bats I caught were male. I captured 8 female northern long-eared bats at one site, including all 7 lactating females from this species. Excluding this site from analysis, 96% of all the bats I captured were male. I did not capture any pregnant or postlactating females, nor any juveniles, at any of the sampling sites.

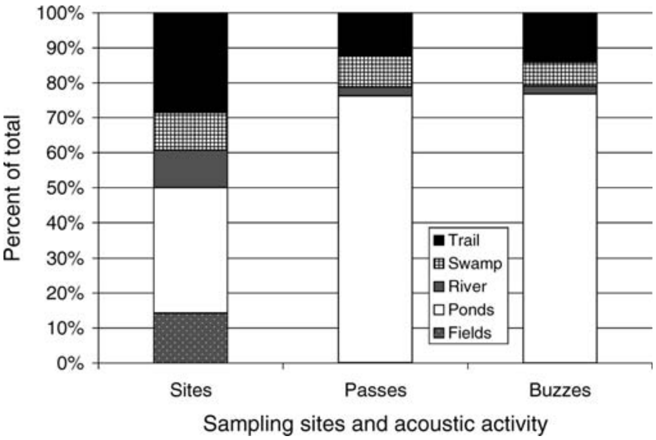

Figure 2. The distribution of sampling sites, total bat passes, and total feeding buzzes by habitat type at the Maple Ridge wind development site, Lewis County, New York, USA, 23 Jun–5 Jul 2004.

Acoustic monitoring.—Although I conducted acoustic monitoring at 35 stations across the project site, 7 sites had technical problems or did not record data for the entire evening and were therefore excluded from analysis. I recorded 4,259 bat passes during 208 detector-hours. However, activity levels were highly skewed across sample sites, with 39.0% of the sample sites having activity levels below 1.0 passes/hour. Therefore, although the mean activity level across the project site was 20.6 passes/hour, the median activity level was 6.2 passes/hour. Bat activity was significantly influenced by habitat ($F_{4,345} = 2.92$, $P = 0.02$), with ponds being the only habitat showing preferential use by the bats (Fig. 2). There was no evidence that the relative activity between habitat types changed throughout the course of the night ($F_{2,345} = 1.54$, $P = 0.22$). The acoustic data suggest the presence of at least 4 species of bats across the project site (Table 2). Bats in the genus *Myotis* accounted for almost 95.7% of the calls and 98.8% of all feeding buzzes. The big brown/silver-haired group represented 3.3% of the calls, and the migratory tree-roosting bats (red bat and hoary bat) accounted for 1.0% of the total activity. Temporal analysis of bat activity showed that most of the big brown/silver-haired group activity occurred early in the evening ($F_{4,355} = 2.91$, $P = 0.02$), with peak activity occurring at 2145 hours (Fig. 3). In contrast, *Myotis* bats were detected throughout the night, with activity levels increasing during the early evening and declining gradually after midnight.

Migratory Activity

Acoustic monitoring.—During 5,328 hours of acoustic monitoring, I identified 459 bat passes (Table 3) for an overall acoustic capture rate of 0.09 bat passes/hour. I found no difference in mean level of bat passes between the Kabinski and Porter sites ($F_{1,250} = 0.06$, $P = 0.82$), therefore I pooled these data. The nightly level of detectable bat activity was highly skewed to the right and had a median activity level of 2.0 bats/night (range: 0–125 bats/night). Although I found the activity levels were generally low, I did record 2 high activity events. One event occurred on 20 April at the Kabinski array. During this event, I recorded 101 bat passes from eastern pipistrelles at the turbine microphone from 2130 to 2200 hours. The second event

Table 2. The number of bat passes and feeding buzzes identified by species or species group across the Maple Ridge wind development site (Lewis County, New York, USA) during the summer breeding season (22 Jun–5 Jul 2004).

Species	Total passes	Sites detected	Feeding buzz	Trails	Ponds	Fields	Marshes	River
Myotis spp.	4,075	22	175	505	3,148	2	319	101
Big brown bat/silver-haired bat group	140	12	2	13	86	2	36	3
Red bat	3	1	0	0	0	0	3	0
Hoary bat	41	10	0	3	10	0	26	2
Eastern pipistrelle bat	0	0	0	0	0	0	0	0
Total	4,259	28	177	521	3,244	4	384	106

occurred on 10 June at the Porter array. During this second event, I recorded 115 bat passes from *L. cinereus* at the ground microphone from 0530 to 0700 hours. Excluding these 2 high-activity events, the big brown/silver-haired group and hoary bats were the 2 most commonly detected species groups, representing 54.4% and 24.5% of total bat passes, respectively. The *Myotis* spp. group, which contained the greatest number of potential bat species occurring at the project site, represented 19.0% of the total bat passes. Although there was bat activity throughout the sampling period, I recorded more bat passes during the late spring sampling period compared to the early spring ($F_{2,251} = 5.00$, $P = 0.01$). There was also a significant difference between species in the seasonal timing of acoustic activity ($F_{8,238} = 6.67$, $P = 0.001$). Calls from the two most commonly detected species groups, big brown/silver-haired bats and hoary bats, were rare during the early spring. Most of the activity in the big brown/silver-haired group occurred during the middle and late spring sampling periods, whereas most of the activity from hoary bats occurred during the late sampling period. The *Myotis* spp. group did not show any significant seasonal variation in activity.

There was a general decline in activity over the course of the night (Fig. 4), with more bat passes early in the evening relative to the middle or late sampling periods ($F_{2,251} = 5.02$, $P = 0.01$). I heard more bat passes at the ground microphone (49% of total bat passes) compared to the supracanopy (34%) and turbine (17%) microphone ($F_{2,251} = 7.46$, $P = 0.001$). There was no interaction between the timing of bat activity and microphone height ($F_{4,251} = 0.51$, $P = 0.73$).

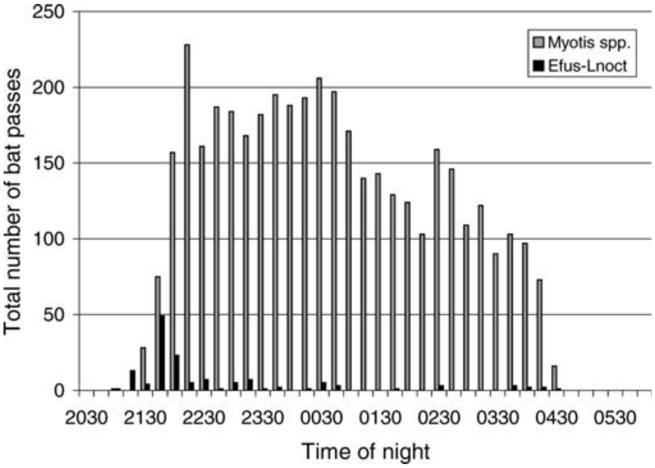

Figure 3. Temporal distribution of bat passes across the Maple Ridge wind development site in Lewis County, New York, USA, 23 Jun–5 Jul 2004. Efus-Lnoct represents the bat passes assigned to the big brown bat/silver-haired bat acoustic group.

Meteorological influence on activity.—Bat activity was negatively influenced by daily minimum wind speed (V_{min}; $F_{3,70} = 9.70$, $P < 0.001$) and daily mean wind speed (V_{ave}; $F_{3,70} = 3.32$, $P = 0.03$), but not daily maximum wind speed (V_{max}; $F_{3,70} = 0.59$, $P = 0.63$) or evening mean wind speed (V_{even}; $F_{3,70} = 0.40$, $P = 0.75$). Most of the migratory activity (medium and high levels) occurred at minimum wind speeds below 1.3 ± 1.1 m/second, whereas days with no bat activity had a minimum wind speed of 3.4 ± 1.4 m/second (Table 4). Except for V_{max} and V_{min}, all the wind speed variables were highly correlated ($r \geq 0.35$, $P < 0.001$).

Temperature appeared to have a strong influence on migratory activity throughout the spring sampling period; however, all the temperature variables were highly correlated with each other ($r \geq 0.50$, $P < 0.001$). High migratory activity was most strongly influenced by daily maximum temperature (T_{max}; $F_{3,70} = 18.87$, $P < 0.001$), although daily mean temperature (T_{ave}; $F_{3,70} = 18.01$, $P < 0.001$), daily minimum temperature (T_{min}; $F_{3,70} = 3.48$, $P = 0.02$), and evening mean temperature (T_{even}; $F_{3,70} = 13.81$, $P < 0.001$) were also significant. Days with high bat activity had a mean maximum temperature of 23.9 ± 4.4°C compared to 9.8 ± 4.8°C for days with no bat activity (Table 4).

During the spring migratory period, the prevailing wind direction at the Porter tower was from the south (mean azimuth of 175.3°). Variation in wind direction over the course of the migratory season had no detectable influence on bat activity ($\chi^2 = 18.2$, $P > 0.50$), with the modal wind direction for all activity classes within the same range (225°–270°).

Discussion

The research I conducted at the Maple Ridge wind development site strongly suggests that the Tug Hill Plateau physiographic region does not support a large bat population in terms of either species diversity or total bat abundance. In particular, the data I collected during the summer show low levels of biodiversity and a highly male-biased sex ratio.

Summer Survey

Net capture.—My mist netting survey result of 0.3 bats per net-night (b/nn) was lower than other published

Table 3. The number of bat passes identified by species or species group at 2 sampling sites on the Maple Ridge wind development site during the spring 2005 migratory season (10 Apr–22 Jun).

	Kabinski			**Porter**		
Species	**Ground**	**Supracanopy**	**Turbine**	**Ground**	**Supracanopy**	**Turbine**
Myotis spp.	19	13	4	5	0	4
Big brown bat/silver-haired bat group	25	16	12	53	11	12
Red bat	2	2	0	1	0	0
Hoary bat	9	21	13	130	0	0
Eastern pipistrelle bat	0	0	101	0	0	0
Total	55	52	130	189	11	16

population surveys, for example 3.5 b/nn (Clark et al. 1987), 7.3 b/nn (Whitaker and Gummer 2001), and 0.6 b/nn (Brack et al. 2004). It is also lower than surveys conducted at other wind development sites, such as 1.5 b/nn (Gates et al. 2004) and 1.0 b/nn (Johnson and Strickland 2003). The low level of species diversity and the high proportion of males that I captured at the project site suggest that the Maple Ridge Wind Power site is marginal habitat for reproductive bats. My capture effort did not provide any evidence for the presence of the two species of concern (*M. leibii* or *M. sodalis*).

Acoustic monitoring.—My acoustic monitoring data shows that most of the bat activity was concentrated around the artificial ponds throughout the project site. This is consistent with previous studies that show several of these species concentrate their foraging activity around water (Fenton et al. 1980, Furlonger et al. 1987, Zimmerman and Glanz 2000, Menzel et al. 2001, Owen et al. 2003, Menzel et al. 2005). The median activity level of 6.2 passes/hour (p/hr) was comparable to other acoustic monitoring surveys in similar habitat and/or elevation from New York (17.3 p/hr; Gannon and Sherwin 2001) and New Hampshire, USA (0.7 p/hr; Krusic 1995). It was also similar to the activity levels detected at other wind development sites in West Virginia (6.0 p/hr; Johnson and Strickland 2003), Iowa, USA (8.3 p/hr; Jain 2005), and Ontario, Canada (4.7 p/hr; Fenton et al. 2004). Although total species diversity was higher based on acoustic monitoring, overall activity across my study area was relatively low.

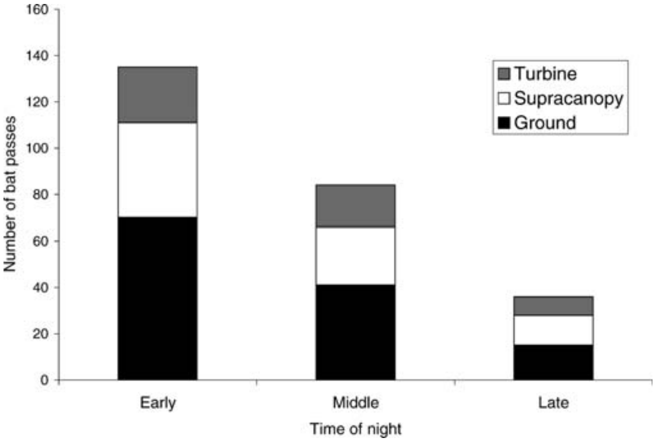

Figure 4. Temporal distribution of bat passes across the Maple Ridge wind development site in Lewis County, New York, USA, during the spring 2005 migratory season (10 Apr–22 Jun). Early is defined as 1900–2300 hours, mid as 2301–0300 hours, and late as 0301–0700 hours.

Overview of summer survey.—The summer data support the first hypothesis of lowered species diversity and overall activity level. The most likely cause of the low activity was the relatively higher elevations and correspondingly lower temperatures and higher precipitation of the Tug Hill compared to the adjacent river valley. Previous research has shown that total species diversity and the total number of individual bats decline with increasing elevation (Fenton et al. 1980, Thomas and West 1988, Krusic 1995, Grindal et al. 1999, Cryan et al. 2000, Brack et al. 2002). Other studies have also found that low temperatures reduce bat activity (Negraeff and Brigham 1995, Vaughan et al. 1997). There was no strong evidence for the predicted shift in community composition towards species that are more commonly found at higher elevations (e.g., the silver-haired bat, big brown bat, and hoary bat), as they comprised only 8.6% of all captures (all big brown bats) and 4.3% of the acoustic passes (mostly hoary bats).

The capture data I collected at Maple Ridge site appeared to be consistent with the general pattern towards male-biased sex ratios at high elevation and high latitude sites (Fenton et al. 1980, Shump and Shump 1982, Ford et al. 2002, Cryan et al. 2004). These data also are consistent with the general reduction in reproductive females captured at high elevation sites (Barclay 1991, Cryan et al. 2000). Therefore, my study suggests that the Tug Hill Plateau did not contain a substantial resident bat population, and with the exception of northern long-eared bats, appeared to be primarily used by males and nonreproductive females.

Migratory Activity

Acoustic monitoring.—My data from the acoustic array suggest that migratory activity across the project site had a highly variable temporal component relative to the spatial component. This suggests that migratory bat activity may be relatively broad-fronted but episodic. The two large migratory events I recorded are potentially very informative. First, they differed in timing by 51 days, suggesting that the migratory season for bats may be extensive. Some species, such as the big brown/silver-haired group and hoary bats, appear to migrate later in the season than *Myotis* spp. Second, the hoary bat event occurred early in the morning at the lowest microphone (7 m above ground), suggesting

Table 4. The influence of meteorological variables on the level of migratory activity (mean ± SD) detected at the Maple Ridge wind development site during the spring 2005 migratory season (10 Apr–22 Jun). Categories with overlapping bars were not significantly different based on a General Linear Model using Tukey's multiple comparisons procedure.

Level of migratory activity[a]	*n*	Mean wind speed ± SD (m/sec)	Mean daily temperature ± SD (°C)	Minimum wind speed ± SD (m/sec)	Minimum daily temperature ± SD (°C)	Maximum wind speed ± SD (m/sec)	Maximum daily temperature ± SD (m/sec)	Mean evening temperature ± SD (°C)
None	19	6.92 ± 1.37	5.35 ± 4.12	3.44 ± 1.40	1.13 ± 3.81	10.16 ± 1.86	9.81 ± 4.78	3.20 ± 3.60
Low	23	5.87 ± 1.88	10.54 ± 5.00	2.33 ± 2.03	4.16 ± 4.63	9.35 ± 2.15	15.87 ± 5.61	8.38 ± 5.27
Medium	20	5.39 ± 1.88	12.59 ± 5.16	1.32 ± 1.17	6.52 ± 5.19	9.41 ± 2.35	18.13 ± 5.64	10.57 ± 5.02
High	12	5.16 ± 1.94	17.96 ± 4.77	0.84 ± 0.84	12.25 ± 6.90	9.84 ± 2.51	23.87 ± 4.45	14.66 ± 6.68

[a] None = 0 bats/night; low = 1–2 bats/night; medium = 3–6 bats/night; high > 6 bats/night.

migratory behavior is highly variable between species and within species under different climactic conditions. The high quality of the calls, the large number of calls per pass (often >20 calls/file), the extensive CF component of each call, and the lack of any shift in call characteristic typical of investigatory behavior or foraging, make me confident that these data represent a series of commuting individuals rather than multiple passes from the same individual (Reynolds, unpublished data). If these calls are typical of migrating bats, then the use of quantitative species identification methods (Britzke and Murray 2000) may not be reliable using existing call libraries.

Although acoustic systems have been used to monitor bat activity above the tree canopy (Bradshaw 1993), there has been little effort to develop higher altitude acoustic monitoring (but see McCracken 1996, Fenton and Griffin 1997, Menzel et al. 2005). Long-term monitoring using vertical acoustic arrays is a new technique that could be better developed specifically to address bat mortality in relation to wind power development. Based on my data, the use of meteorological towers (met towers) as an array platform shows promise for 3 reasons. First, met towers are sized to match the height of the wind turbines (currently up to 80 m in height), thereby allowing researchers to sample migratory behavior within the proposed rotor sweep zone. Second, met towers are located within the proposed project area up to 3 years prior to turbine installation, thereby allowing us to collect long-term site-specific data within the project area. Lastly, met towers have trails and service roads leading to them, and these trails and the edge habitat created by the clearing will provide ideal travel corridors to monitor ground-level bat activity.

The primary advantage of the method I employed is that acoustic monitoring can be conducted across a variety of habitats and in multiple configurations depending on the deployment of met towers. My study protocol also addressed 2 of the major concerns regarding many acoustic monitoring protocols: 1) the lack of vertical sampling, and 2) the lack of long-term monitoring (Hayes 2000). Without a high altitude microphone, it is likely that the large eastern pipistrelle migratory event would have been missed due to the inability to detect these calls from the ground. Additionally, without a complete season of monitoring effort, it is likely that both this high-activity event and the hoary bat migratory event would have been missed completely.

The main detraction of acoustic monitoring is the difficulty of identifying species with overlapping acoustic signatures such as the *Myotis* bats found in the Northeast (Ahlen 2004, Jones et al. 2004). However, the primary goal of my study was to document the spatial and temporal distribution of the entire bat community and not just for an endangered species such as the Indiana bat. When species discrimination is conducted using conservative techniques, acoustic monitoring continues to be one of the best sampling methods available (Britzke et al. 2002).

The influence of weather on bat migratory activity.— One of the most promising methods of minimizing bat mortality is the development of an adaptive management plan that would be able to curtail turbine activity during periods of peak bat migration activity. Recent data collected in West Virginia have suggested that bat migratory passage rates are higher during evenings with low wind speed (Arnett 2005). I found that most of the bat migratory activity occurred when the daily mean wind speeds were below 5.4 m/second. This is encouragingly close to the cut-in speed (the lowest economically useable wind speed) of a typical commercial wind turbine (Danish Wind Industry Association 2003). Temperature also had a significant influence of the migratory activity, with no detectable migratory activity when the daily mean temperature was below 10.5°C. Bats may be using these 2 meteorological indicators on different temporal scales, as temperatures during the night (between 1900–0700 hours) significantly influenced migratory activity, but wind speeds during the night did not. I found that wind direction did not influence migratory activity. This may make sense if the bats rely on low wind speed conditions during migration.

Management Implications

The development of BWEC is a critical first step to identify key research questions and help establish methodologies that answer those questions and generate data that can be compared across a region. However, more effort needs to be made to assess the direct threat of wind development to bats; namely the risk of migratory bat activity across a project site and whether nonmigratory flight on the project site poses a significant threat of turbine collision. The data I collected suggest there is more risk of bat mortality during the migratory season compared to the summer months due to higher levels of activity at turbine height. Given the high growth rate of wind development and the political pressure to obtain a clean and reliable energy source, quicker deployment of valid presiting survey protocols seems prudent.

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