To the Graduate Council:

I am submitting herewith a thesis written by Jenny K. Fiedler entitled "Assessment of Bat Mortality and Activity at Buffalo Mountain Windfarm, Eastern Tennessee." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Wildlife and Fisheries Science.

David Buehler
Major Professor

We have read this thesis
and recommend its acceptance

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Accepted for the Council:

Dr. Anne Mayhew
Vice Chancellor and Dean of Graduate Studies

(Original signatures area on file with official student records)

ASSESSMENT OF BAT MORTALITY AND ACTIVITY AT BUFFALO MOUNTAIN WINDFARM, EASTERN TENNESSEE

A Thesis
Presented for the
Master of Science Degree
The University of Tennessee, Knoxville

Jenny K. Fiedler
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ABSTRACT

Wind power has grown rapidly as an alternative energy source over the last decade. Although overall environmental impacts are relatively low, impacts to bats have yet to be fully assessed. Recent studies at other windfarms suggest regional variation in mortality rates and species affected. This study took place at Tennessee Valley Authority's Buffalo Mountain Windfarm (BMW) in eastern Tennessee, currently the only commercial windfarm in the southeastern United States. Study objectives were to establish patterns of bat mortality and activity at BMW, and determine if and how they were related.

Mortality monitoring consisted of regular carcass searches conducted since BMW began operation in fall of 2000 and continued through fall of 2003. The adjusted bat mortality rate of 20.82 bats/turbine/year for the three-year monitoring period was greater than the average adjusted bat mortality rate at eight other windfarms (1.7 bats/turbine/year) by over an order of magnitude, but less than half the preliminary mortality rate (47.5 bats/turbine/year) reported at the Mountaineer Wind Energy Center, WV for 2003. The BMW mortality rate included adjustments determined by search bias trials ($n = 6$), which measured searcher efficiency (37.1%) and length of time before carcasses were removed by scavengers (average 6.3 days). Average distance of fatalities from turbines was 19.9 ± 2.3 m and distances of bat fatalities decreased logistically from turbines ($y = 0.1223 - 0.1345 \ln(x)$, $r^2 = 0.84$, $P = 0.0002$), with zero fatalities predicted at 40.6 m; therefore, plot size of 50 m radius was deemed sufficient. Bat mortality showed a strong seasonal peak during late summer / early fall, with 70% of all bat fatalities occurring between 1 August and 15 September 2001 - 2003. A total of 119 bat fatalities were comprised of six species. Red bat (*Lasiurus borealis*) was the most common (63.1%), followed by eastern pipistrelle (*Pipistrellus subflavus*, 24.4%) and hoary bat (*L. cinereus*, 10.1%). The remaining 4.2% of bat fatalities consisted of three species: big brown bat (*Eptesicus fuscus*, n = 2), silver-haired bat (*Lasionycteris noctivagans*, n = 2), and Seminole bat (*L. seminolus*, n = 1). Adults were more common then juveniles (63.5% and 36.5%), and males more common than females (71.9% and 28.1%).

Bat activity was monitored with Anabat bat detectors and quantified as activity indices (AI), the proportion of one-minute increments in a night that contained one or more recorded bat calls. AI's were compared across several time periods, locations, and altitudes, and compared with bat mortalities. Bat activity exhibited a seasonal peak in late summer / early fall during all three years, generally coinciding with the peak in mortality. Some of the variance associated with the likelihood of mortality was correlated with bat activity for 2002 and 2003 combined ($r = 0.47$, $P < 0.0001$). Considering only fresh fatalities, bat activity levels were greater during nights containing fatalities than nights without fatalities ($t = 2.54$, $P = 0.0067$). However, bat activity was not related to fatalities when the time interval was expanded from individual nights to search intervals and all fatalities were used ($t = -1.05$, $P = 0.15$). This suggests great variation in bat activity between nights, making temporal resolution an important factor when correlating levels of bat mortality and activity. Bat activity levels were influenced by presence, size and habitat configuration surrounding water features, as well as by altitude. Six species were acoustically identified as present at the BMW site, five of which were found among the turbine fatalities. Three species were found proportionally less as turbine fatalities than were acoustically recorded (eastern pipistrelle, big brown bat, and silver-haired bat) and two species were found proportionally more (red bat and hoary bat), indicating a greater collision risk for the latter species.

Overall numbers of bat fatalities at BMW, along with the lack of endangered species fatalities, indicate that population effects appear not to be significant. However, as the generation of electricity from wind increases in the eastern United States, it becomes critical to understand patterns in turbine-related mortality, and for future windfarm projects to determine population level effects of bat mortality.

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I. INTRODUCTION

Interest in the development of wind energy as an alternative energy source in the United States has increased over the last two decades (Energy Information Administration 1993, AWEA 2002). The number of megawatts produced by wind energy in the United States has more than doubled in the last three years. Thirty-two states currently have wind generation facilities, and one more has proposed facilities (AWEA 2004). Although wind energy provides the benefit of clean and renewable energy, environmental costs, such as impacts on flying vertebrate populations, have not been thoroughly researched. Recently documented avian interactions with wind energy facilities have focused attention on incidental reports of bat mortalities at these same structures (Erickson et al. 2001, Keely et al. 2001, Erickson et al. 2002).

Although most of the developed wind power and 90% of the wind power potential within the United States exists in 12 midwestern and western states (Weinberg and Williams 1990, Figure 1, all figures are located in Appendix A), a narrow region following the Appalachian Mountain ridgeline and extending into eastern Tennessee has shown good to excellent potential for wind resource development (Elliott et al. 1986, Figure 2). Presently, 21% of the developed wind power exists in the states east of the Mississippi river, but a significant portion of the wind industry's current growth is planned for the East. Fifty-two percent of proposed wind-derived generation capacity is located in the eastern United States (AWEA 2004). Regional differences in avian mortality rates and species compositions at windfarms have already been documented; such differences are unknown for bats but may also exist (Erickson et al. 2002). Factors such as topography, climate, habitat, species composition and relative abundances, species-specific behavior, and seasonal animal movements could affect bat mortality rates at windfarms in different regions of the country.

Despite the relatively recent documentation of bat mortality at windfarms, there is a long history of bat mortality associated with other human-made structures. Bat collision mortalities at human-made structures have been reported most commonly at communication towers (Van Gelder 1956, Anonymous 1961, Ganier 1962, Gollop 1965, Avery and Clement 1972, Taylor and Anderson 1973, Zinn and Baker 1979, Crawford and Baker 1981). Other reports include a lighthouse (Sauders 1930), tall buildings (Terres 1956, Mumford and Whitaker 1982, Timm 1989), barbed wire fences (Johnson 1933, Iwen 1958, Hibbard 1963, Hitchcock 1965, DeBlase and Cope 1967, Denys 1972, Wisely 1978, Fenton 2001), power lines (Dedon et al. 1989), and vehicles (Kiefer et al. 1995).

Bat interactions with wind energy facilities were first noted in Australia, initially by Tate (1952), and then by Hall and Richards (1972). Tate (1952) recorded two crippled white-stripped mastiff bats (*Tadarida austalis*) at the base of windmills and speculated the moving blades had injured them. Hall and Richards (1972) found 22 fatalities of white-stripped mastiff bats over a four-year period at other windmills and noted that fatalities of other, more common bat species were not found. Johnson et al. (2003a) reported that bat fatalities have also been found at wind energy facilities in Sweden (Ahlen 2002), and Germany (Bach 2001).

Within the United States, small numbers of bat fatalities were first recorded at several wind energy projects in California during avian mortality monitoring (Howell and Didonato 1991, Orloff and Flannery 1992, Howell 1997, Anderson et al. 2000, Thelander and Rugge 2000). As wind power developed in other states, bat mortalities became documented in Minnesota (Johnson et al. 1999, 2000a, and 2003b), Oregon (Erickson et al. 2000 and 2003a, Strickland et al. 2000 and 2001, Johnson et al. 2003c), Colorado (Kerlinger et al. 2000), Iowa (Erickson et al. 2002, Johnson et al. 2003a), Wisconsin (Howe et al. 2002), Wyoming (Gruver 2002, Young et al. 2003a & b), Washington (Erickson et al. 2003b), Pennsylvania (Kerlinger 2001), and West Virginia (Kerns and Kerlinger 2004). Mortalities rates however, measured in number of bat fatalities per turbine per year and adjusted for search biases, have been calculated at only seven windfarms, and ranged from 0.1 to 4.3 (Table 1, all Tables are located in Appendix B). An eighth wind project in West Virginia however, recently reported a preliminary, adusted mortality rate of 47.5 bats / turbine / year (Kerns and Kerlinger 2004).

Currently, more information is known about interactions with human-made structures for birds than for bats (Erickson et al. 2001). At tall structures, factors commonly speculated to affect avian mortality include structure height, presence of lights, presence of guy wires, and inclement weather during migration (Manville 2000). Although flight is a characteristic shared between birds and bats, differences such as the ability to echolocate, nocturnal foraging, migration patterns, and roost-site preferences may cause differences in bat use of wind resource areas compared with bird use. Some wind energy projects have already shown differences in levels of bird versus bat mortality (Erickson et al. 2001), but specific mechanisms explaining bat collisions with wind turbines have yet to be described.

Information on bat fatalities at other structures may provide clues as to why bat mortality is occurring at windfarms. Bat fatalities at three types of tall structures (building, lighthouse, and communication tower) were comprised of nine species: red bat (*Lasiurus borealis*; 83), silver-haired bat (*Lasionycteris noctivagans*; 28), hoary bat (*L. cinereus*; 26), Seminole bat (*L. seminolus*; 17), northern yellow bat (*L. intermedius*; 9), Mexican free-tailed bat (*Tadarida brasiliensis*; 2), big brown bat (*Eptesicus fuscus*; 1), little brown bat (*Myotis lucifugus*; 1), southeastern bat (*M. austroroiparius*; 1), with red bat being the most common across all locations (Sauders 1930, Terres 1956, Van Gelder 1956, Anonymous 1961, Ganier 1962, Gollop 1965, Avery and Clement 1972, Taylor and Anderson 1973, Zinn and Baker 1979, Crawford and Baker 1981, Timm 1989).

The vast majority of bat fatalities were found from August through October, although this may be in part because many were found in conjunction with large avian kills at the same structures. Weather conditions were rarely noted in these reports, but Sauders (1930) and Van Gelder (1956) found bat fatalities on nights with rain, fog, or overcast skies, along with large avian mortality events. However, Crawford and Baker (1981) conducted the most comprehensive study over a 25-year period and reported that bat fatalities at a television tower were found during both clear and overcast nights, as well as with and without large avian mortality events. Migration was commonly speculated as a factor contributing to the bat fatalities at these structures.

Other early speculations explaining bat mortality at tall structures came from Van Gelder (1956), who proposed that the echolocation systems of bats might receive interference with television transmitters, or from migrating birds forced to lower altitudes during adverse weather conditions. Although several researchers (Van Gelder 1956, Crawford and Baker 1981, Timm 1989) have suggested that bats might not echolocate during migration, essentially making them susceptible to the same collision factors affecting migrating birds (weather, landscape features, migration corridors, etc), no evidence has been presented to support this statement. Crawford and Baker (1981) also proposed that bats might be foraging upon insects attracted to the Federal Aviation Administration (FAA) lighting required on many human-made structures.

Mechanisms responsible for bat mortality at tall structures may be similar to mortality mechanisms at wind energy facilities, although the turbine's large moving blades may add an additional, significant risk factor. Hall and Richards (1972) speculated that a bat's echolocation frequency might become synchronous with a rotating propeller under certain conditions and effectively make turbines invisible to the bat. Crawford and Baker (1981) suggested that lattice support structures might provide roosting sites for bats, increasing the amount of bat activity near turbine blades.

Johnson et al. (2003a) reviewed bat fatalities at U.S. windfarms, and summarized both the species composition (at ten windfarms) and seasonality (at seven windfarms) of bat fatalities; preliminary results from this study were included in the results. Johnson et al. (2003a) reported six species as turbine fatalities: hoary bat (61.1%), eastern red bat (18.3%), silver-haired bat (8.6%), big brown bat (2.7%), eastern pipistrelle (*Pipistrellus subflavus*; 2.2%), and little brown bat (2.1%). Unidentifiable carcasses made up an additional 5.0%. The three most common species were foliage roosting bats and composed the vast majority of the fatalities found at windfarms (88.0%). Two windfarm studies have reported additional mortality results since the Johnson et al. (2003a) report. Nine Canyon Wind Project, WA had similar results with two foliage roosting bats comprising all bat fatalities: 15 silver-haired bats (56%), and 12 hoary bats (44%) (Erickson et al. 2003b). Preliminary mortality estimates from the Mountaineer Wind

Energy Center, WV however, found all six species reported previously as well as a seventh (northern long-eared bat, *Myotis septentrionalis*) among the fatalities: red bat (42.1%), hoary bat (18.5%), eastern pipistrelle (18.3%), little brown bat (12.6%), silver-haired bat (5.9%), northern long-eared bat (1.3%), big brown bat (0.4%), and unknown (0.8%, Kerns and Kerlinger 2004). The two foliage roosting bats (red bat and hoary bat) were again the most common, but greater proportions of eastern pipistrelle and little brown bat, along with an additional *Myotis* species create a different species composition at the West Virginia windfarm than seen at other windfarms. The bat activity data gathered thus far with mist-netting and bat detectors at U.S. windfarms indicate that bat species common as summer residents are responsible for the majority of activity, yet species that are less common as residents and are also migratory (i.e., red bat, hoary bat, and silver-haired bat) make up the greater part of mortality (Gruver 2002, Johnson et al. 2003a).

Phenology of fatalities at the seven windfarms extended from early May through mid-November, but peaked during August (53.2%); July and September contained the next greatest numbers of fatalities (21.9 and 18.8%, respectively; Johnson et al. 2003a). Nine Canyon Wind Project, WA had a similar peak with 48% found during September (Erickson et al. 2003b). The majority of the bat fatalities at Mountaineer Wind Energy Center, WV were between mid-August and the end of September (92.5%, Kerns and Kerlinger 2004). The strong seasonality of bat fatalities found across all windfarms seems to confirm late summer / early autumn as a critical time period. As with other tall structures, migration has been suggested as an important factor in bat mortality at wind turbines (Erickson et al. 2002). However, no study has documented the reason for bat collisions at tall structures. Besides migration, other autumn activities include breeding, swarming, dispersal, and stopover activity related to migration such as foraging, drinking, and roosting.

Additional factors that may affect collision mortalities were considered at some windfarms. Researchers at Klondike Wind Project, OR and Nine Canyon Wind Project, WA found fewer bat fatalities at turbines with lighting, but differences were not statistically significant (Erickson et al. 2003b, Johnson et al. 2003a). Stateline Wind Project OR/WA (Erickson et al. 2003a), Buffalo Ridge Wind Resource Area (WRA), MN (Johnson et al. 2000b) and Mountaineer Wind Energy Center, WV (Kerns and Kerlinger 2004) reported similar numbers of bat fatalities at turbines with and without lights. Young et al. (2003a) at Foote Creek Rim Wind Plant, WY studied the differences in avian fatalities at turbines with blades painted with either UV (n = 72 turbines) or non-UV reflective paint (n = 33 turbines). In their study, bat fatalities were incidentally recorded, and the majority occurred at turbines with blades painted with UV reflective paint (88%). Turbine position within a row of turbines was suggested to affect the number of raptor fatalities, with conflicting reports of greater numbers at both end row and mid-row turbines (Orloff and Flannery 1996, Anderson et al. 2000, Erickson et al. 2003a). Again, bat fatalities were recorded incidentally during a study at the Nine Canyon Wind Project, WA and results were very similar for end row and mid-row turbines (Erickson et al. 2003b). The age and sex of bat fatalities have only been reported at Buffalo Ridge WRA, MN where the majority of fatalities were adults, and male fatalities slightly outnumbered female fatalities (Johnson et al. 2003a).

Inclement weather has also been suggested as a possible cause for both bird and bat mortality at tall structures (Manville 2000, Erickson et al. 2002). Reports have consistently linked very large avian fatality events at communication towers (numbering in the thousands of dead birds) with significant weather events. However, most studies done at windfarms have used search intervals between two and four weeks, and therefore lack the temporal resolution needed to link bat fatalities with specific weather events. Studies at Foote Creek Rim wind plant, WY, Klondike wind plant, OR, Buffalo Ridge WRA, MN, and Mountaineer Wind Energy Center, WV considered weather prior to fresh fatalities and found no relationship to inclement weather (Young et al. 2003b, Johnson et al. 2003c, Johnson et al. 2000b, and Kerns and Kerlinger 2004, respectively).

Current information on bat mortality at windfarms comes entirely from windfarms in the western or midwestern United States, with the exception of some preliminary results from Mountaineer Wind Energy Center, WV. The majority of the information gathered to date may not be relevant to the East because of regional differences in topography, climate, habitat, species composition and abundances, and season animal movements. Regional differences in species composition and seasonality of kills already exist for birds and may also exist for bats (Erickson et al. 2001). Tennessee Valley Authority's (TVA) Buffalo Mountain Windfarm (BMW) in eastern Tennessee began operation in October 2000 and is the only operating windfarm in the southeastern United States (AWEA 2004). Because wind turbine interactions with bats specific to the Southeast are virtually unknown, BMW provides a unique opportunity to assess the degree of regional differences.

More information is needed before bat mortality at windfarms is fully understood, and until then, it is even more critical to consider the status of bat species in an area when assessing the impact of a wind energy facility. In regards to BMW, fourteen species of bats occur in Tennessee, two of which are federally listed as endangered: gray bat (*Myotis grisescens;* USFWS 1976, 41 FR 17740), and Indiana bat (*M. sodalis*; USFWS 1967, 41 FR 41914). A third species, southeastern bat is considered a "Species of Concern" by the US Fish and Wildlife Service, and Rafinesque's big-eared bat (*Corynorhinus rafinesquii*), is considered "in need of management" by the Tennessee Wildlife Resources Agency (TWRA, Tennessee code annotated sections 70-8-104 and 70-8-107). When assessing the environmental impacts of windfarms in this region, extra consideration must be given to the behavior (foraging, roosting, and migration) of these four species.

Ten other bat species also occur in Tennessee, although lack of appropriate microhabitat may preclude their use of BMW study site (Barbour and Davis 1969, Table 2). These ten species include five foliage roosting species - red bat, Seminole bat, hoary bat, silver-haired bat, and evening bat (*Nycticeius humeralis*), and nine species that utilize caves or rock cervices for at least part of the year: small-footed bat (*M. leibii*), little brown bat, northern long-eared bat, eastern pipistrelle, big brown bat, and the four species with some type of federal or state status (gray bat, Indiana bat, southeastern bat, and Rafineque's big-eared bat). The silver-haired bat is the only bat species not residing in Tennessee during the summer, usually occurring in the Southeast only during migration and winter (Choate et al. 1994, Cryan 2003).

The two endangered bat species, gray and Indiana, are both cave-dwelling bats. The Indiana bat utilizes caves primarily for winter hibernation, whereas the gray bat is dependent on caves year-round, although usually different caves in summer and winter. The closest known location of a significant number of gray bats is a small maternity roost (approximately 5000 bats) about 25 km away from BMW in Campbell County, TN. Individual records of gray bats have also been documented in Anderson, Roane and Campbell counties (Travis Henry, TVA, pers. comm.), and caves known to contain gray bats include two summer caves in Union and Claiborne counties and a year-round cave in Hawkins County (Harvey and Pride 1986). Indiana bats utilize caves in Tennessee primarily for winter hibernation, and most females of this species migrate north of the state to form nursery colonies. The closest known hibernaculum for Indiana bats exists approximately 50 km away from BMW in Campbell County (~300 bats); other nearby hibernaculums include one in Claiborne County, two in Blount County, and four in Fentress County (Harvey and Pride 1986, Travis Henry, TVA pers. comm.). A summer nursery has recently been discovered in the Nantahala National Forest in western North Carolina (USDA 2002), and another in the Great Smokey Mountains National Park in eastern Tennessee (Britzke et al. 2003). Individual records of Indiana bats have not been recorded in any county surrounding BMW except Campbell County.

My study has three main objectives. The first is to document the extent of bat mortality at BMW and then examine the mortality for spatial, temporal, and species patterns. To put the bat mortality into an appropriate context, the second objective is to determine bat activity at BMW using bat detectors and mist-netting. A final objective is to determine relationships between bat activity and mortality at the BMW site.

II. STUDY AREA

BMW is a three-turbine facility situated on 0.8 ha (2 ac) of ridge top in Anderson County, Tennessee, approximately ten km north of Oliver Springs and 50 km northwest of Knoxville (36° 7' 15.6" N, -84° 20' 19.4", Figure 3). BMW is on top of Buffalo Mountain, at an elevation of just under 1010 m (3300 ft), and similar to the peak height of surrounding ridges. Buffalo Mountain lies approximately ten km northwest of Walden Ridge, the eastern escarpment of the Cumberland Plateau. BMW is contained within the Cumberland Mountain Section of the Appalachian Plateau Physiographic Province and consists of ridges and valleys (Fenneman 1938).

This portion of the Cumberland Mountains is marked with extensive disturbance from previous mining activities. The top of Buffalo Mountain was mined for coal, and the wind turbines are positioned on a reclaimed strip mine. The site is relatively flat and open with gravel, planted grasses, forbs, and some small trees and shrubs. Vegetation at the windfarm site is dominated by species planted during mine reclamation: Sericea lespedeza (*Lespedeza cuneata*), tall fescue (*Festuca* spp.), and other introduced herbaceous species. Black locust (*Robinia pseudoacacia*), red maple (*Acer rubrum*), and an additional species not planted during reclamation, yellow poplar (*Liriodendron tulipifera*), make up a sparse tree cover generally < 10 m (33 ft) tall. A small depression wetland (< 0.4 ha) left by mine reclamation activities lies approximately 75 m (246 ft) east of two of the turbines. Dominant vegetation at the wetland includes cattail (*Typha latifolia*) and soft rush (*Juncus effusus*). Nearby undisturbed areas contain mature and second growth oak (*Quercus* spp.)-hickory (*Carya* spp.) forests and scattered pines

(*Pinus* spp.) on south or southwestern slopes, and mixed-mesophytic forests on moister slopes (Tennessee Valley Authority 2000).

The area has a moist, temperate climate. The annual average precipitation of Anderson County is 140 cm (55 in) and annual average snowfall is 28 cm (11 in, USDA 1981). Average temperature ranges from 4ºC (39ºF) in winter to 24ºC (75ºF) in summer; average minimum temperature in winter is –1ºC (30ºF) and maximum in summer is 30ºC (86ºF, USDA 1981). Bailey et al. (2003) reported that prevailing winds at BMW are from the southwest or south-southwest and annual wind speed at hub height (65 m) was 6.80 m/s (15.2 mph) between 2000 and 2002. Annually wind speeds were greatest in winter and early spring and least in summer, wind speeds were also greater at night.

Construction of the three wind turbines was completed in September 2000 and electrical generation began in October 2000 and continues to present. BMW consists of three Vestas V47 wind turbines manufactured by Vestas-American Wind Technology Inc. (Ringkøbing, Denmark). The type and size of these turbines are representative of many of the wind turbines currently in use at other United States windfarms. Each turbine has a 47 m (154 ft) diameter, 3-blade rotor mounted on a 65 m (213 ft) tall tubular steel tower. Total maximum height of the turbines is 88.5 m (290 ft) when a blade is in the 12 o'clock position. The rotor-swept height is from 41.5 to 88.5 m (136 and 290 ft) and total rotor-swept area is 1,735 m^2 (18,675 ft^2) for each turbine. The rotors begin spinning at a wind speed of 2 m/s (4 mph) and start to generate electricity at 4 m/s (9 mph). Once generating, the turbines maintain a constant speed of 28.5 revolutions per minute and generate 660 kilowatts of power at peak wind resistance. Total facility capacity for the three turbines is 1.98 megawatts of power. Two white strobe lights on top of each turbine consistently flash 40 times/min. The candlepower of these lights is 20,000 during the day and 2,000 during the night.

The turbines are aligned in a north-south orientation and are spaced 108 and 136 m (354 and 446 ft) apart. For the purposes of this study, one control plot (C1) was located on the same ridge at the wind turbines, about 150 m (492 ft) northeast of the northern-most turbine. Two additional control plots (C2 and C3) and a meteorological tower (M1) were located about 400 – 600 m (0.25 to 0.37 miles) immediately northwest of the turbines on an adjacent ridge (Figure 4). The meteorological tower is 60 m (197 ft) in height, supported by guy lines in three directions, and has no lights.

III. BAT MORTALITY AT BUFFALO MOUNTAIN WINDFARM

INTRODUCTION

The mechanisms explaining bat mortality at wind turbines are poorly understood. We may derive clues, however, from a long history of bat mortality at other human-made structures including lighthouses, communication towers, buildings, transmission lines, vehicles, and barbed wire fences (Avery et al. 1980, Kerlinger 2000, Erickson et al. 2001, Johnson et al. 2003a). Among bat mortality at tall, stationary structures, seasonality was the most consistent characteristic. Most of the fatalities occurred during late summer / early autumn, a pattern also seen at eight windfarms that have monitored for bat mortality (Johnson et al. 2003a, Erickson et al. 2003b, Kerns and Kerlinger 2004). Another consistency was the species affected; although 45 species of bats inhabit North America, only nine have been documented fatalities at human-made structures, and only six of which have documented fatalities at wind turbines; three species made up 80% of the windfarm fatalities (hoary bat, red bat, and silver-haired bat; Johnson et al. 2003a, Erickson 2003b, Kerns and Kerlinger 2004). All three species are common, wide-ranging bats that migrate long distances, and are foliage roosters. The strong seasonality of bat mortality has made migration a commonly cited factor related to bat mortality, and one already proven as important for songbird mortality at human-made structures (Kerlinger 2000). However, other factors significant for avian mortality at windfarms, such as presence of FAA lighting, position of wind turbines within a windfarm, and inclement weather, have not been found to be important for bat mortality (Kerlinger 2000, Erickson et al. 2003a & 2003b, Johnson et al. 2003a, 2003c, Kerns and Kerlinger 2004). More information on bat mortality at windfarms is needed to elucidate possible mechanisms and risk factors. This information will provide better site-selection criteria for windfarms and help evaluate possible impacts of windfarms on bat populations, potentially preventing significant impacts of a growing industry on populations already experiencing declines (Kunz and Racey 1998).

Tennessee Valley Authority's (TVA) Buffalo Mountain Windfarm (BMW) in eastern Tennessee began operation in October 2000 and is the only operating commercial windfarm in the southeastern United States. Currently, the closest windfarm is in West Virginia, which began operation in 2002 (AWEA 2004, Kerns and Kerlinger 2004). Regional differences in species composition and seasonality of kills already exist for birds and may also exist for bats (Erickson et al. 2001). Because wind turbine interactions with bats specific to the Southeast are virtually unknown, BMW provides a unique opportunity to assess the degree of regional differences. My study had the following objectives:

1. Document bat mortality at BMW wind turbines with systematic searches;
2. Determine spatial, temporal and species patterns of bat mortality;
3. Estimate mortality rates by recording observer and scavenger biases at turbine and reference plots.

METHODS

Mortality Monitoring

This study encompassed a three-year monitoring period that began in late September 2000 when construction at BMW was essentially complete, and concluded at the end of September 2003. Field assistants and I conducted carcass searches twice weekly between 1 April and 1 November during this three-year period, with the exception of summer 2001 (15 May to 15 August) when searches were conducted weekly. In addition, searches were conducted weekly during the months of November and March, and bi-weekly during December, January, and February.

During each visit 7 plots were searched; one centered on each of 3 wind turbines, one centered on a nearby, 60-m, guy-wired, meteorological tower, and three nearby control plots. Each plot was a 50-m-radius circle, and was systematically searched by at least two searchers walking linear transects approximately 5 m apart. Wooden stakes placed in a 10-m grid during the summer of 2002 helped guide searchers during subsequent searches.

When carcasses were found, the following information was recorded before the specimen was bagged, labeled, and transported to TVA freezer facilities: date found, searcher names, plot ID, unique code for specimen, distance and bearing from plot center, condition (noting injuries, as well as any decay or scavenging evidence), and when possible, species, age, and sex. The night of death was estimated based on carcass decomposition, as well as the presence and degree of insect scavenging in context of recent weather conditions. Starting in 2002, I assigned a degree of injury to carcasses using the following criteria:

0 = no observable external injuries;

1 = small wounds, tears in membrane, or bruising, but no broken bones; and

2 = any broken bones, and/or any major wounds.

Patterns of Bat Mortality

Spatial Mortality Patterns

I calculated the average distance a bat carcass was found from a turbine. Number of bat fatalities at each of the three turbines was compared for all years combined since no differences between years was expected. With only three turbines, differences in mortalities because of turbine position (row end or middle) were not tested.

Temporal Mortality Patterns

Seasons were based on bat biology and included: spring migration (1 April to 15 May), summer residency (16 May to 15 July), fall migration (16 July to 30 September), and the period encompassing low or no bat activity and hibernation (1 October – 31 March). Average daily mortality rates, calculated as the average number of bat fatalities per day, were compared for these four time periods. I pooled fatalities into half-month groups to examine annual patterns of mortality.

Species, Age, and Sex of Fatalities

Bat carcasses were keyed out according to Schwartz and Schwartz (1981). I determined age using the developmental changes in the cartilaginous growth plates of the fourth metacarpal-phalangeal joint (Anthony 1988), and sex based on external morphology (Racey 1988).

Windfarm Generation Effect

Based on initial observations of some bat carcasses with little or no observable external injuries, I hypothesized that the extent of the injuries sustained may be correlated with the windfarm generation during the night of the fatality. Electrical generation data for BMW were collected and processed by American Weather Service (AWS), a contractor of TVA. Daily windfarm generation (in KW-hours) was recorded at 0800 daily so that one "day" covered an entire night of bat activity. Windfarm generation (total KW-hours) was plotted against number of bat fatalities found for each month. I calculated the correlation between the degree of injury and the daily KW-hours produced by the windfarm, using bat carcasses fresh enough to be confidently assigned to a single night (Table 3) during the peak six-week mortality period (1 Aug – 15 Sep) in 2002 and 2003 (PROC CORR, SAS 2001). Using the same time period, I also evaluated the relationship between KW-hour production and the occurrence of a bat fatality event for those nights when the presence or absence of a bat fatality could be confidently assigned based on carcass decomposition. Data achieved normality when log transformed, and I used PROC TTEST (SAS 2001) to test for differences.

Predictive Weather Parameters

AWS collected weather data every ten minutes from the meteorological tower on site at BMW; all parameters were measured at a height of 30 m (98 ft). Parameters included wind speed (m/s), wind direction (degrees), and temperature (°C). TVA personnel calculated an average, a minimum, and a maximum value for each parameter during four six-hour periods (2400 – 0600 hours, 0600 – 1200 hours, 1200 – 1800 hours, and 1800 – 2400 hours). The values from the last six-hour period of a day and the first six-hour period of the next day were used for one night's weather.

Logistic regression was used to identify possible explanatory variables to predict nights when a fatality event would likely occur. Since 92% of all fatalities were concentrated during July through October of each year, I initially used data from those four months in this analysis. However, results of a preliminary logistic regression analysis selected month as a significant predictor variable, so the time period was further narrowed to 1 August – 15 September, a period containing 70% of the mortalities, and month was eliminated as a potential explanatory variable. I only selected nights during 2002 and 2003 that I could confidently categorize as either having or not having a fatality event based on degree of decomposition on individual fatalities (Table 3). Nights of probable death were assigned to fatalities showing moderate to extreme decomposition; these nights and a buffer of one night previous were excluded from the analysis.

Potential explanatory variables examined included daily generation of the windfarm, average wind speed, average wind direction, average temperature, minimum and maximum temperature between 1800 and 0600 hours, and the difference between the minimum and maximum temperature. Average wind speed, wind direction, and temperature measured during three time periods (1800 – 2400 hours, 2400 – 0600 hours, and 1800 – 0600 hours) were also included as potential variables. The difference between the first two periods (first and second halves of each night) was also calculated as variables for average wind speed and direction to describe variation within one night. Wind direction was measured in azimuth degrees (0-360°), and then transformed using the following equation:

$$A' = \cos(A_{\max} - A) + 1$$

where A' is the transformed degree code, $A_{\max}$ is the degree to which was assigned the highest numerical value on the transform scale (0 to 2.00), and A is the degree which was transformed. This transformation enables the inclusion of circular data as an independent variable by weighting observations closer to a chosen direction or aspect

(Beers et al. 1966). Northeast (45°) was assigned to $A_{\max}$, giving it a value of 2 and Southwest, the predominant wind direction at BMW annually and during autumn, a value of zero.

Because correlations were expected between many of the variables, groups of highly correlated variables were identified with a correlation matrix of all 16 independent variables (NCSS 2002). Variables with a Spearman correlation coefficient ≥ 0.5 were considered correlated. To avoid multicolinearity, only one of a group of highly correlated variables was selected (e.g., nightly average, minimum, and maximum temperature, average temperature in the first and second half of a night, and the temperature difference between the two halves, were all highly correlated). The results from a simple logistic regression of individual variables in each group against the occurrence of mortality were used to select the independent variables to be included in the logistic regression.

I first conducted a stepwise selection procedure with very high alpha values (P = 0.99) and chose the optimal number of predictor variables from the model with the lowest Akaike's Information Criterion (AIC). AIC is an information theoretic approach to variable selection that is not based on arbitrary alpha values (Burnham and Anderson 1998). I then conducted a best subset selection procedure on all possible models with $\pm$ two predictor variable from the optimal model. For example, if the optimal number of variables from the stepwise procedure had three predictors, a best subset regression was performed on all models with 1, 2, 3, 4, and 5 predictor variables (Shtatland et al. 2001). From this subset, I analyzed the variables selected for all models within two AIC values of the optimal model with the lowest AIC value. All logistic regression procedures were carried out using PROC LOGISTIC (SAS 2001).

Carcass Search Biases

Actual mortality was undoubtedly greater than observed because of biases such as searcher efficiency in finding carcasses and / or carcass removal by scavengers. The influence of these factors may have varied by individual searcher, proximity and density of scavengers in the area, and changes in vegetation structure between seasons and/or years (Rosene and Lay 1963, Balcomb 1986, Tobin and Dolbeer 1990). To account for these biases, six search bias trials were conducted between September 2001 and July 2003.

Non-searchers planted between 10 and 34 bat and/or bird carcasses on search plots the evening before a scheduled search. Carcass distances and bearings from plot center were determined with a random number generator. Planted carcasses were labeled with plastic tags attached with wire to bird legs or bat wings. Labels were hidden beneath the carcasses, and searchers did not know the dates of the search bias trials beforehand. During the initial search, searchers recorded carcasses found and any evidence of scavenging, but did not remove the carcasses. Written locations of planted carcasses were made available to searchers immediately following the initial search, and searchers attempted to locate all labeled carcasses not found and determined whether they had been missed or scavenged. Presence during subsequent searches was used to determine amount of time a carcass remained. Based on decomposition rates observed on site, remaining carcasses were monitored for 20 days.

I tested for differences in searcher efficiency and scavenging rates during trials based on carcass type (bird or bat) using 2-sample t-tests (SAS 2001). Scavenging rates were log transformed to meet normality requirements. The small number of trials did not allow tests for differences in season and related vegetation structure (n = 6 trials).

Searcher Bias

Searcher efficiency (*p*) of each search bias trial was expressed as the proportion of the planted carcasses not removed by scavengers that were found by searchers during the initial search. Searcher efficiencies were calculated separately for each of the six trials, as well as for carcass type (bird, bat, and combined), but pooled across plot type (turbine, control, and tower) because habitat was similar for all plots. The associated variance was calculated following methods from Johnson et al. (1999), which assumes correlation between the number of carcasses found by observers and the number of carcasses placed in the study. The variance (*V*) of the average searcher efficiency was calculated by the formula:

$$V(p) = p^2 * \left[\frac{V(f)}{f^2} + \frac{V(k)}{k^2} - 2 * \rho \frac{se(f)se(k)}{(f)(k)} \right]$$

where *k* is the total number of carcasses placed, *f* is the number of carcasses found by the observers, and ρ is the correlation between k and f across trials. A 90% confidence interval was calculated using this variance and a critical value from the Student's t-distribution with n-1 degrees of freedom because of the small sample size.

Scavenger Removal Bias

Carcass removal time was calculated as the number of days between the time the carcass was planted and the last search date it was observed, plus half the days between when it was last observed and when it was determined removed. A few carcasses persisted on site and were not scavenged. Based on observations of the condition of the planted carcasses that persisted, 20 days was selected as a termination date for the carcass removal trials. I calculated removal bias ($\bar{t}$) following methods by Erickson et al. (2003a) using the following equation:

$$\bar{t} = \frac{\sum_{i=1}^{S} t_i}{S - S_c}$$

where t_i is the length of time a carcass remained on site, S is the total number of carcasses planted for the study and S_c is the number of planted carcasses that remained at 20 days. This is a maximum likelihood estimator assuming removal times followed an exponential distribution. Using a termination length of 20 days makes the data right-censored, and may lead to an underestimation of the actual scavenging rate and mortality estimates. Removal times were calculated for birds, bats, and combined carcasses, but pooled across plot type to establish removal rates for each trial. Overall scavenging rates at BMW were pooled across trials since the number of trials was not large enough to determine seasonal differences. The associated variance was calculated using the exact variance of the maximum likelihood estimate of $\bar{t}$:

$$Var(\bar{t}) = \frac{1}{n}\left(\bar{t}^2 - 2T_c\bar{t}e^{-T_c/\bar{t}} - \bar{t}^2 e^{-2T_c/\bar{t}}\right)$$

where n is the total number of carcasses planted and T_c is the fixed censored time (20 days). This variance is appropriate for censored data and free from a large sample assumption (Barnard 2000). A 90% confidence interval was calculated using this variance and a critical value from the Student's t-distribution with n-1 degrees of freedom because of the small sample size.

Scavenger Detection and Identification

I determined the effect of scavenging by noting the presence of partial scavenging on carcasses found during searches, as well as calculating scavenging rates observed during search bias trials. Two separate methods were used to identify possible scavengers: track plots and motion-triggered cameras. I used 1-m diameter track plots to document the presence of potential mammalian scavengers at the BMW site from fall of 2001 through fall of 2002 (Wilson et al. 1996). Curiosity lures consisting of a piece of tinfoil attached with string to a stick were used rather than scent lures to increase the detection of area scavengers while preventing the attraction of additional animals. Because of limitations of the track plots to detect smaller or non-mammalian predators, I placed motion-triggered cameras near planted bird or bat carcasses from fall 2002 through fall 2003. Casual observations of possible scavengers, tracks, and scat during study-related activities were also noted and used to supplement the list of possible area scavengers compiled from the two previous methods (Wilson et al. 1996).

Plot Size Bias

Using distance from turbine, I grouped number of bat carcasses into 5 m intervals and then calculated density of bat fatalities per meter squared for each group to correct for area. To determine if the 50-meter-radius plot was a sufficient search area, I used regression analysis to predict the distance at which zero fatalities would be found (PROC REG, SAS 2001).

Crippling Bias

An additional source of bias exists when animals crippled by turbine-collision move out of the area and die. This bias is very difficult to estimate (Gauthreaux 1996), thus collision victims still found alive were noted but this bias was not incorporated into mortality adjustment rates.

Estimation of Mortality Rates

The estimated number of bat fatalities at BMW was calculated using the observed number of fatalities and adjusting for two biases, searcher detection and scavenging removal, both calculated from the search bias trials (Mayer 1995). The estimated number of fatalities (*m*) during a given time period was calculated following methods presented by Johnson et al. (2003b).

$$m = \frac{N * I * C}{k * \bar{t} * p}$$

where *N* is the total number of turbines, *I* is the interval between searches in days, *C* is the total number of carcasses found, *k* is the number of turbines sampled, $\bar{t}$ is the mean length of time carcasses remained on site before scavenged, and *p* is searcher efficiency. All three turbines were searched every time, therefore, *N/k* always equaled one. Mortality rates were estimated using the estimated number of bat fatalities per year for each year starting 1 October and ending 30 September; the three years were averaged to yield an overall windfarm adjusted morality rate. Overall variance, standard error, and 90% confidence interval were calculated using the standard formulas for a sample mean on the mortality estimates for the three years.

RESULTS

Mortality Monitoring

Between 26 September 2000 and 30 September 2003, carcass searches were conducted at BMW on 215 dates (Table 4) and a total of 120 bat fatalities of six species were found (Table 5). Not all bats were used in all analyses (Table 6). Four bat fatalities were found on turbine plots during other activities and two were found outside of the 50-m-radius plot perimeters; information on these fatalities were recorded but excluded from mortality estimates and spatial analyses. Five bats were still alive when found and because of their possible mobility, these bats were excluded from spatial analyses. A scavenged red bat was found in a control plot and classified as a probable mist-net fatality from nearby trapping efforts the previous night, and consequently excluded from all analyses.

Patterns of Bat Mortality

Spatial Mortality Patterns

The average distance of bat carcasses from a turbine was 19.9 ± 2.3 m (SE). The numbers of bat fatalities found at each turbine were similar (T1, n = 37; T2, n = 37; T3, n = 36) as were species-specific differences in mortality among turbines for the three most common species detected during carcass searches (Table 7).

Temporal Mortality Patterns

The majority of bat fatalities (82.4%) occurred during the July / September time period for 2001, 2002, and 2003 (Table 8). The mean number of fatalities per night for the windfarm during four time periods were: April / May, $\bar{x} = 0.01$, May / July, $\bar{x}$ =

0.07, July / September, $\bar{x}$ = 0.42, October / March $\bar{x}$ = 0.01. All of the fatalities during the latter period were during the month of October (n = 6). Seventy percent of bat fatalities occurred in a month and a half period (46 days, 1 August – 15 September) and 96% occurred during an 88-day period centered on 22-23 August (Table 9; Figure 5). Although biweekly carcass searches were conducted 1 December to 1 March no fatalities were found.

Species, Age, and Sex of Bat Fatalities

Six species were identified among the bat fatalities found at BMW (Table 10). Red bats made up the majority of bat fatalities overall (61.3%, n = 73), as well as for each year. Eastern pipistrelles and hoary bats, respectively, were the next two most common bat fatalities overall (24.4%, n = 29 and 10.1%, n = 12, respectively), but proportions differed by year. During 2001 and 2003, the eastern pipistrelle made up a larger proportion than the hoary bat (2001, 29.0% vs. 3.2%; 2003, 39.5% vs. 4.7%), but the reverse was true during 2002 (6.8% vs. 20.5%). The remaining 4.2% of the bat fatalities consisted of three species: big brown bat (n = 2), silver-haired bat (n = 2), and Seminole bat (n = 1).

Of the carcasses that could be sexed (74.8%), bat fatalities were comprised of more males than females for all years pooled (males 71.9%, females 28.1%), as well as annually (Table 11). Twenty-five percent of the bat carcasses could not be sexed because of varying degrees of decomposition and / or injuries. Of the bat fatalities that could be confidently aged (81.5%), adults made up 63.5% and juveniles 36.5% (Table 11). Aging was occasionally complicated by extensive decomposition and injuries, and by juveniles having adult-like characteristics of epiphyses in September and October. Age and sex proportions of the three most commonly found species did not differ than those observed for all species. Adults were almost twice as common as juveniles, and males were over twice as common as females (Table 11).

Windfarm Generation Effects

Annually, months of low winds and less windfarm generation were June through September, which encompassed the annual peaks in bat mortality (Figure 6). On a nightly basis, amount of daily windfarm generation was not correlated with the degree of injury sustained by a bat ($n = 23$, $r = -0.03$, $P = 0.91$, Figure 7). Daily generation also did not differ on nights when bat fatalities occurred ($n = 15$) versus nights when fatalities did not occur ($n = 37$) from 1 August – 15 September 2002 and 2003 ($t = 0.13$, $P = 0.89$).

Predictive Weather Parameters

Nine models with 2 to 5 explanatory variables were assessed because they were within $\pm$ two AIC values of the best AIC model. Four of the six potential variables were consistently included in the nine models: average nightly wind speed (-), wind speed difference (-), average nightly wind direction (+), and maximum temperature (-) (Table 12). The positive association with wind direction indicated that the greater the difference between wind direction and the predominant wind direction (SW), the greater the chance of a fatality event. The other three variables were negatively associated, thus the greater the nightly wind speed, maximum temperature, and difference between the average wind speeds during the first and second portion of the night, the chance of a fatality event decreased.

Carcass Search Biases

Biases for each of the six carcass bias trials were calculated separately for birds, bats, and all carcasses (Table 13). I found no difference in searcher efficiency for bird versus bat carcasses (t = 0.23, P = 0.82) or scavenging time for bird versus bat carcasses (t = 0.12, P = 0.91). Seasonal differences could not be tested because of a small sample size (n = 6 trials). Thus, the bias rates for all carcasses types were combined. Habitat was similar for turbine, control and meteorological tower plots, and results were pooled across plot type.

Observer Bias

Searcher detection rates for all carcasses were highly variable and ranged from 9.09 to 75.00% for the six trials. The mean was 37.0% (n = 151, df = 5, 90% CI = 10.6, 63.4%).

Scavenging Removal Bias

The average number of days a scavenged carcass remained on site for the six trials ranged from 3.2 to 16.7 days. Given the small number of trials (n = 6), all carcass types, plot types, and trials were pooled, and the average number of days before a carcass was scavenged was 6.3 days (n = 151, df = 5, 90% CI = 6.0, 6.7).

Scavenging Evidence

Thirteen possible scavenger species were identified on site at BMW (Table 14). Five mammals were detected from tracks left in track plots: coyote (*Canis latrans*), red fox (*Vulpes vulpes*), raccoon (*Procyon lotor*), bobcat (*Lynx rufus*), and feral cat (*Felis catus*). Motion-triggered cameras identified mice (*Peromyscus spp.)* in addition to coyote. Visual sightings and casual observations of scat or tracks outside of the track plots detected coyote, raccoon, bobcat, and added four reptilian species: timber rattlesnake (*Crotalus horridus*), northern copperhead (*Agkistrodon contortrix*), black ratsnake (*Elaphe obsoleta*), and cornsnake (*E. guttata*). Possible avian scavengers observed in the area included American crow (*Corvus brachyrhynchos*), turkey vulture (*Cathartes aura*), and black vulture (*Coragyps atratus*). Although none of these methods represent a comprehensive survey of potential scavengers in the area, more evidence (e.g., tracks) was noted throughout 2002 then either 2001 or 2003, particularly for coyote (Table 14).

During the search bias trials, an average of 36% of the planted carcasses were removed from the site before the search the next morning (~12 – 16 hours; Table 15). The number of days a planted carcass remained on site averaged 6.3 days when all trials were pooled. Partial scavenging was found on 6% of the planted carcasses remaining the next morning (Table 15). Scavenging by insects was rarely noted on planted carcasses and was therefore not included. Unlike planted carcasses, scavenging by insects was noted frequently on actual fatalities (mostly maggots and small ants, and occasionally carrion beetles), but the relatively short search interval rarely made insect scavenging a significant factor in actual removal of the carcass. Although additional search bias trials would be needed to detect seasonal or yearly differences, overall scavenging on planted carcasses appeared to be greater throughout 2002 based on greater initial scavenging during search bias trials, fewer average days before a carcass was scavenged (Table 15) and more casual observations of scavenger tracks at the site during that year.

Plot Size Bias

Once corrected for area and expressed as density, the distance of fatalities from turbines fit a non-linear curve best ($y = 0.1223 – 0.1345 \ln (x)$, $r^2 = 0.84$, $P = 0.0002$, Figure 8), and results of the regression analysis showed that bat fatalities decreased to zero within 40.6 m, although we found 5 (4.5%) fatalities beyond this distance.

Crippling Bias

Five bats were found alive during the study period (Table 6, 16). Four live bats were found during regular searches and one was found outside the search plot (73 m from turbine 2) during non-search activities. All five bats had sustained significant injury and were euthanized on site (University of Tennessee Animal Care and Use Committee protocol #561).

Mortality Rate Estimations

The four bats found on turbine plots during non-search activities and two bats found outside the plot perimeter were excluded from the following mortality estimations (Table 6). Because no bat fatalities were detected on control plots, no adjustment for background mortality was made. Annual estimates of bat fatalities and mortality rates increased the observed numbers by 48-67%, but were consistent across years (Table 17). The overall observed number of 114 bat fatalities increased to an estimated 187 once both scavenging and observer biases were accounted for. The overall adjusted mortality rate for BMW was 20.82 bats per turbine per year (90% CI = 19.5, 22.1; Table 18). Note that the variance used for this confidence interval is from mortality estimates from three years, and does not account for the variance associated with the search biases (searcher efficiency and scavenger removal time).

DISCUSSION

Patterns of Bat Mortality

Seasonality had the strongest effect on bat mortality at BMW throughout the three-year study period. The vast majority of the bat fatalities occurred during a six-week period stretching from early August to mid-September. This strong seasonality in bat mortality was observed at five other windfarms having significant numbers of bat fatalities (Johnson et al. 2003a, Kerns and Kerlinger 2004).

Increased movements of bats occur during the late summer / early autumn as a result of several activities including migration, dispersal, swarming and / or breeding activity (Fenton and Thomas 1985). These activities often overlap, for example, breeding for most North American temperate bats occurs in autumn, during migration for some species and during swarming prior to hibernation for other species. The movements resulting from these activities may contribute to the increased exposure of bats to wind turbine collisions, but overlap of these activities also make it difficult to pinpoint a particular activity based on seasonal occurrence of bat fatalities alone.

Three of the six bat species made up 96% of the turbine fatalities found at BMW: red bat, eastern pipistrelle, and hoary bat. All three are common residents of the Southeast. The red bat and hoary bat are both widespread, foliage roosting species that are known to migrate long distances (Barbour and Davis 1969). These two species are also the two most common species found among fatalities at eleven other windfarms (hoary 47.2%, red 24.2%, Johnson et al. 2003a, Erickson et al. 2003b, Kerns and Kerlinger 2004). Although few specifics such as migration altitudes are known, flight behavior during seasonal migration likely puts bats into the critical air space swept by wind turbine blades. The eastern pipistrelle is often the most common species in much of its' range within the eastern United States, and inhabits mostly caves and rock crevices, although it roosts mainly in trees during summer (Barbour and Davis 1969). The easterly distribution of this species probably explains the relatively low occurrence of this species at other windfarms, occurring only at windfarms in Minnesota (Johnson et al. 2003a), and West Virginia (Kerns and Kerlinger 2004). Long distance migrations have not been recorded for this species, but swarming has (Barbour and Davis 1969). Swarming, a localized concentration of bats flying around places such as caves, has been noted during autumn and thought to be related to breeding activity as well as familiarizing young bats with hibernacula (Fenton 1969). However, unless a known swarming place is close to a windfarm, it seems unlikely that any breeding-related behavior is responsible for windfarm mortality.

The remaining three species killed at BMW were silver-haired bat, big brown bat, and Seminole bat. The silver-haired bat is another relatively long-distance migratory species that is commonly found among fatalities at other windfarms in the western and midwestern United States (Johnson et al. 2003a). Uncommon in the Southeast for much of the year, the range of this species extends into the Southeast mostly during migration and winter, possibly explaining the single silver-haired bat fatality found on 1 October 2001 (Cyran 2003). Dispersal is the most likely explanation for the sole Seminole bat fatality at BMW. Not found among fatalities at any other windfarm, the Seminole bat is strictly a species of the Southeast, with the northern range limit of this species extending slightly into southern Tennessee approximately 100 km south of BMW (Kennedy et al. 1984). Although not considered migratory, southward shifts during autumn and winter have been observed for this species (Barkalow 1948). Extensive wandering has also been documented during September and October with records in Pennsylvania and New York (Poole 1949, Layne 1955, Wilkins 1987). As at BMW, the big brown bat has only been found occasionally at other windfarms (Johnson et al. 2003a), and is considered a sedentary species. Based on species and seasonality of bat mortality, migration and / or dispersal may be important factors in bat mortality at windfarms.

Certain shared characteristics of the most commonly killed bat species may elucidate possible risk behaviors. For example, bat morphology corresponds to flight behavior; wing loading and aspect ratio are two measures of wing morphology that reflect where and how a species forages (Altringham 1996). Wing loading is the weight of the bat divided by the total area of the flight membrane: high wing loading corresponds to a relatively large bat in comparison to the size of the wings. These bats generally have narrow wings and are fast fliers. Aspect ratio refers to the shape of the wing; low aspect ratio corresponds to short and broad wings capable of greater maneuverability in high vegetation clutter, whereas high aspect ratio corresponds to long and narrow wings reflecting strong, fast flight, but less maneuverability. These different measures reflect a trade-off between maneuverability and strong, fast flight. Two of the three most common bat fatalities at BMW, red bat and hoary bat, and a third species commonly killed at other windfarms, the silver-haired bat, all have high wing loading and medium to high aspect ratio. These bats are more able to forage in open spaces and are strong enough fliers to resist some wind. Based on their wing morphology, these bats are more likely to utilize and occupy the open spaces where wind turbines are situated, and are also known to migrate long distances. Lastly, these three species are all solitary foliage roosters. Unless species commonly roosting in caves or buildings have suitable structures available near windfarms, they are less likely to inhabit these areas. Foliage roosters, however, are much more spread over the landscape, not being as limited to certain structures.

The age and sex ratios of bat fatalities may also reflect risk factors for certain groups of bats at windfarms, for example, inexperienced juveniles or female bats at nearby maternity roosts. Both adults and juveniles were among the fatalities at BMW, with a greater proportion of adults (63.5%). Buffalo Ridge WRA, MN also reported a greater proportion of adults (88%). Although young bats may be more prone to accidents because of their unskilled flight (Altringham 1996), this does not seem to be the case at either windfarm. Information on population structures would be needed to indicate greater risk for either age class, however, there is a paucity of this information, and age and sex ratios fluctuate with season. Results from two mist-netting surveys, however, do indicate lower proportions of juveniles in Mississippi (red bat – 34%, eastern pipistrelle – 28%) from late April to early September (Miller 2003), and in Iowa (2 adults per juvenile among roosting red bats) during late July and early August (Constantine 1966). Bats reproduce relatively slowly; eastern pipistrelle, red bat, and hoary bat all bear an average of only two young per year (Barbour and Davis 1969). Further evidence of relatively low numbers of juvenile bats comes from juvenile to adult female ratios of red bats during mist-netting surveys between May and September in Louisana (1.9), and Missouri (2.6, LaVal and LaVal 1979).

Of those bats fatalities at BMW for which sex could be determined, 71.9% were male and 28.1% were female, indicating that males may be at greater risk. However, it is not uncommon for different sexes of bats to occupy entirely different regions of the country during summer residency (e.g., silver-haired bat and hoary bat, Cryan 2003). Ford et al. (2002) also found that males dominated red bat museum records in the eastern United States, occurring disproportionately in the Appalachian Highlands where monthly mean maximum temperatures were lower than in either the Central Lowlands-Interior Low Plateaus or Coastal Plain-Piedmont regions. Representative surveys at a specific site would be needed to determine sex ratios that could indicate greater risk for either sex.

Potential Causes of Windfarm Bat Mortality

It is unknown why bats, with both their visual and echolocation abilities, collide with wind turbines, or are hit by the moving blades. Studies with captive bats have shown that bats are better able to discern moving objects compared to stationary ones (Jen and McCarty 1978). Although some have suggested that bats may not echolocate during migration (Van Gelder 1956, Timm 1989), evidence to support this speculation is lacking. Although communication towers and tall buildings have been recorded as sources of mortality, no bat fatalities were reported at meteorological towers searched simultaneously with turbines at Foote Creek Rim Wind Plant, WY (6 towers, Young et al. 2003b), Klondike Wind Project, OR (1 tower, Johnson et al. 2003c), Buffalo Ridge WRA, MN (13 towers, Johnson et al. 2003a), and this study (1 tower). The moving blades may be the important difference. However, amount of daily windfarm generation did not differ on nights with and without bat fatalities at BMW, although blades can still rotate without generating electricity. Additionally, 29% of the bat fatalities found at BMW during 2002 and 2003 had no observable external wounds, although the remainder showed significant injuries consistent with being struck by a moving turbine blade.

Degree of injury was also not correlated with amount of night windfarm generation at BMW. Bats may be both flying into, and being struck by the moving blades; simply flying into a wind turbine as if it were any tall structure may explain the portion of bats sustaining little visible injury.

Inclement weather has been correlated with many large avian mortality events at tall structures during migration (Kerlinger 2000). Four weather variables measured at BMW were consistently included in logistic regression models predicting occurrence of bat fatalities: average nightly wind speed (-), wind speed difference (-), average nightly wind direction (+), and maximum temperature (-) (Table 12). The positive association with wind direction indicated that the further the nightly wind direction was from the predominant wind direction (SW), the greater the chance of a fatality event. The presence of more northerly winds during fatal nights may be related to weather conditions conducive for bat migration. Negative associations with the other three variables indicated that fatality occurrence was more likely during slightly cooler nights with calmer, less variable winds, although differences in these parameters on fatal and non-fatal nights may not be biologically significant (Table 19). Although occasional storms occurred throughout each period of peak mortality, bat fatalities were much more common than storm occurrence and were distributed relatively evenly. Bat carcasses were backdated to 37% of the nights during the six-week mortality peak. Furthermore, no large mortality events were found, like those commonly seen for avian mortality at communication towers. So although migration seems related to the bat mortality at windfarms, there does not seem to be an association with inclement weather.

Regional Windfarm Differences

The mortality rate at BMW was high compared to most other windfarms, but less than half the preliminary mortality rate reported at the closest windfarm (Mountaineer Wind Energy Center, WV). Mountaineer Wind Energy Center, WV is also the only other windfarm situated along a prominent ridgeline in a forested landscape with exposed rocky areas. There are several factors that may contribute to the greater mortality rate found at these two sites. First, there may be simply more bats present as a result of either greater overall abundances of bats in the southeastern and / or mid-Atlantic states, or some characteristic may be attracting a concentration of bats. For example, the combination of a prominent ridgeline, surrounding forests, and exposed rocky areas offering roosting habitat may cause increased exposure of bat populations to collisions with wind turbines. Because the turbine type used at BMW is similar to turbines used at other windfarms, a turbine type-specific cause seems unlikely. These turbines are also representative of the modern turbines used at current windfarms, with tubular support towers and other modifications minimizing possible roosting places for bats.

Differences in search methods and frequency as well as adjustment calculations may obscure relationships in mortality rates between windfarms that would enable the isolation of factors responsible for increased rates of bat mortality. These factors include number and type of turbine, presence of lighting fixtures required by the FAA, climate, macro- and micro-habitat habitat features, landscape content and context, macro- and micro-topography features, and regional species composition and abundances. With only three turbines, BMW is smaller than most commercial windfarms. Although the mortality rates allow comparisons between windfarms in a cursory way, ultimately it is important to consider the total number of turbines, the subsequent total number of bats killed, and finally, the effect of the number of fatalities on area populations in any impact assessment. Given the overall numbers of bat fatalities at BMW, along with the lack of endangered species fatalities, there does not appear to be significant effects on bat populations in the BMW area.

Carcass Search Biases

Searcher efficiency and scavenging rate were two biases used to adjust estimates of observed windfarm mortality. These two biases and several other potential biases, including search interval, background mortality rates, crippling bias, plot size, and seasonal vegetation cover, are considered important factors in estimating the number of bat fatalities found by observers. There are three ways these biases affect estimated mortality rates: 1) the likelihood an available carcass is found, 2) the likelihood the carcass is available to be found, and 3) the likelihood the carcass is actually a turbine collision. The effects of these biases merit further discussion.

Differences between individual searcher efficiency, vegetation structure on plots, and carcass size all affect carcass detection rates. Morrison (2002) reported searcher efficiency was "highly variable" among windfarms, ranging from 35-85%. Searcher efficiency at BMW was also highly variable (range 9-75%, n = 6 trials). Ground cover and individual searcher ability all contributed to the searcher efficiency at BMW. Search plots at BMW were periodically bush-hogged and hand-cleared to remove vegetation and increase visibility. The number of search bias trials was not sufficient for statistical tests, but the effect of vegetation density on searcher efficiency at BMW was probably significant. Morrison (2002) also reported larger carcasses were more likely to be found by searchers at some windfarm studies. The range in size between the largest bat (hoary bat, 25-30 g) and the smallest bat (eastern pipistrelle, 6-8 g) is relatively small compared to the range in sizes of birds. To capture the appropriate detection bias caused by size, search bias trials at BMW reflected the small size of most fatalities at BMW and consisted mostly of bats and small birds, although a few medium-sized birds were used. Studies with significant variation among searcher ability, vegetation, and carcass sizes should calculate different rates for those categories.

The availability of a carcass to be found depends on search interval, plot size, crippling bias, and scavenging rate. The twice-weekly search interval that was conducted for this study is the most intensive search effort reported for any windfarm in the country. Most other windfarms conducting avian and/ bat mortality monitoring conduct searches at two or four-week intervals, leaving more time for carcasses to disappear through decomposition or scavenging. More frequent searches provided the resolution needed to assign at least some bat fatalities to a specific night, allowing associations with environmental conditions that were highly variable. Nonetheless, frequent searches are not always logistically possible, especially at large windfarms, resulting in decreased precision in estimates of biases and mortality rates.

Small plot size can also decrease the availability of carcasses. Gauthreaux (1996) considered an area adequate if very few or no animals were found near the perimeter of the search plot, and suggested a minimum diameter of 70 m, increasing with turbine height. When compared to communication towers, wind turbines may require search plots with larger diameters as moving blades may deflect animals further distances. The average distance of a bat fatality from a turbine at BMW was 19.9 ± 2.3 m (SE).

Regression analysis on fatality distances predicted zero fatalities beyond 40.6 m, only 5 bats (4.5%) were actually found beyond this distance, suggesting the search radius was adequate at the BMW site. Windfarms with taller turbines should increase the search radius and will have to define an acceptable error rate.

Crippling bias was not considered during this study, but may introduce an additional bias if crippled animals either hide themselves in thicker vegetation and are more difficult for observers to spot, or move off the site completely and are unavailable to be found (Gauthreaux 1996). Five injured bats were found during this study. All had sustained injuries significant enough that searchers determined they would not survive. Three of the bats were directly at the turbine base, and a fourth was 35 m away. The fifth bat however, was over 70 m away from the nearest turbine, which is well beyond the search plot radius. Theses anecdotal observations indicate that a small percentage of bats were missed because of crippling biases. Assuming crippled bats became fatalities, this would bias mortality rates on the low side.

Scavenging rates on turbine fatalities are highly variable and substantial at some windfarms, with 50-75% loss of small to midsize birds within one to four weeks (Morrison 2002). Morrison (2002) also found that carcass size and season influenced scavenging rates. Scavenging at BMW may have varied by carcass size, but this bias was not detected because all bird and bat fatalities found at BMW were small or mid-sized (< 100 g, no raptors were found). Therefore, only small bird and bat carcasses, and a few mid-sized bird carcasses were used during the search bias trials to accurately reflect any size bias. Scavenging did likely vary over time at BMW, although small sample sizes precluded seasonal and related vegetation structure variation from being measured. A difference in scavenging rates of birds and bats has been suggested (Kerns and Kerlinger 2004), but significant differences were not found in this study.

Scavenging rates were much greater during 2002 than 2001 or 2003, with approximately half the planted carcasses being scavenged before the search the next morning and much shorter average scavenging times (Table 15). Potential scavengers included a variety of mammals, reptiles and birds. Based on the increased prevalence of coyote tracks and scat at BMW during 2002, one or more coyotes regularly visiting the site during that year may have been responsible for the increased scavenging. Tracks plots initially used onsite did not attract or capture the tracks of small mammals such as mice, but motion-triggered cameras used during 2002 and 2003 indicated mice visited planted carcasses more often than coyotes. Although partial scavenging of carcasses possibly attributable to mice was noted on both planted carcasses (6%), and actual fatalities (9% of bats during 2002), insects and their larva were the most prevalent partial scavengers. However, the search interval was short enough that although maggots obscured initial injuries sustained by the bats and sped up decomposition of carcasses, insect scavenging did not affect the availability of the carcass to be found by observers. Although no scavenging by snakes was observed, snakes are documented scavengers (DeVault and Krochmal 2002) and were also very common at the BMW site.

Establishing background mortality levels is important to avoid overestimating turbine casualties if carcasses counted could be remains from either predators or other sources of mortality such as vehicle collisions. Background mortality at BMW was assessed using twice-weekly searches at three control plots conducted in conjunction with the turbine plot searches. Other than a bat carcass classified as a mist-net fatality, no bat fatalities were found on the control plots. Background mortality rates using reference plots have only been assessed at one other windfarm (Buffalo Ridge Wind Resource Area, MN), but only birds were found (Erickson et al. in review). Most of those avian fatalities found on the reference plots were associated with either vehicle collisions or predator prey remains. Given that no bat fatalities and only one confirmed avian case could be attributed to a predator rather than the turbines or meteorological tower, background mortality for bats was negligible for BMW at this time. However, if the number of roads and vehicular traffic increases at BMW, background mortality may become a measurable source of mortality for birds as it is at Buffalo Ridge, MN, and possibly for bats. Kiefer et al. (1995) reported vehicular traffic along major roads in Germany as a source of bat mortality, but it is doubtful that the relatively low levels, and mostly diurnal traffic experienced at most windfarms could ever become of a significant source of mortality for bats.

As described above, several biases may affect estimates of bat mortality rates at windfarms. There include searcher efficiency, scavenging rates, search interval, background mortality rates, crippling bias, plot size, and seasonal vegetation cover. It is important for individual windfarms to estimate these biases and their precision when calculating mortality rates, as both regional and site-specific variables can influence them.

IV. BAT ACTIVITY AT BUFFALO MOUNTAIN WINDFARM

INTRODUCTION

Species and temporal mortality patterns of bat mortality at windfarms allow some conjecture of risk factors for certain groups of bats, but information on bat use of the area is needed to place bat mortality into an appropriate context. Bat use may elucidate species, time periods, or behaviors of greater risk for turbine collisions. Ultimately, if clear relationships between bat activity and mortality are found, evaluation of bat use of an area may provide an index of potential bat mortality prior to windfarm development.

Although over 250 wind energy projects are currently operating in 32 states (AWEA 2004), only 11 windfarms have conducted bat mortality studies (Erickson et al. 2002, Kerlinger 2001, Erickson et al. 2003a, Johnson et al. 2003a, Schmidt et al. 2003, Kerns and Kerlinger 2004), and only four of those windfarms also collected data on bat activity at the site (Gruver 2002, Johnson et al. 2003a, Schmidt et al. 2003; Table 20). Two additional windfarms in Oregon conducted bat activity studies prior to construction (Hayes and Waldien 2000 as cited by Erickson et al. 2003a). Four of the six activity studies gathered no, or only limited bat activity information relating to bat mortality. Two studies however, did collect sufficient data on both bat mortality and activity to begin looking at possible relationships between bat activity and mortality at windfarms.

Gruver (2002) determined bat activity at the Foote Creek Rim wind plant in Wyoming with mist-netting, acoustical recordings, and radio telemetry of a focal species. At the Buffalo Ridge Wind Resource Area in Minnesota, Johnson et al. (2003a) measured bat mortality and studied bat activity using both mist-netting and acoustical techniques. The most striking similarity between these two studies is the lack of correlation between the species composition captured by mist-nets and that of turbine fatalities. Gruver (2002) found that the hoary bat made up 88.1% of turbine fatalities at FCR, WY but the same species made up only 6.5% of mist-net captures and 7.8% of acoustical recordings. Similarly, Johnson et al. (2003a) reported hoary bats composed 65.0% of all turbine fatalities at Buffalo Ridge, MN, but only 2.9% of mist-net captures. The prevalence of migratory species among turbine fatalities indicates greater risk for this group of bats. The presence of large, nearby populations of non-migratory bats species not commonly found among turbine fatalities at both Buffalo Ridge, MN and a windfarm in NE Wisconsin adds further supporting evidence for greater risks to migratory than non-migratory bats (Johnson et al. 2003a).

A general pattern of late summer / early fall bat mortality has been reported at seven windfarms, where 86.2% of fatalities occurred from mid-July through mid-September, and 53.2% occurred during the month of August (Johnson et al. 2003a). Using acoustical monitoring, Johnson et al. (2003a) found greater bat activity during this time period at Buffalo Ridge, MN in 2001 and 2002. The number of bat passes per turbine per night increased from an annual average of 2.1 to 3.5 in late July and 3.0 in early August. However, bat activity at turbines with fatalities was not significantly different from bat activity at turbines without fatalities.

Additional bat activity results at Buffalo Ridge, MN indicated that bat activity was much greater at potential foraging and roosting areas, such as upland habitats (e.g., woodlots, farmsteads) and aquatic habitats (59.3 and 26.4 bat passes per turbine per night, respectively) than onsite near wind turbines (2.1 bat passes per turbine per night; Johnson et al. 2003a). Johnson et al. (2003a) also found that distance of turbines from woodland was the only significant habitat factor positively associated with bat activity at wind turbines. Schmidt et al. (2003) found greater bat activity onsite at the National Wind Technology Center, CO at the one plot that had the most trees and was near a rocky outcropping possibly offering roosting structure. Researchers using acoustical monitoring at the Condon proposed wind plant, OR found overall low bat activity but noted considerable activity at stream and pond sites (Erickson et al. 2002). These activity studies suggest that certain microhabitats offering foraging opportunities, drinking water, or roosting structure may attract and concentrate bat activity. It is not known if this increase in activity translates to increased collisions with wind turbines.

Another spatial feature influencing bat activity levels is altitude (Lance et al. 1996, Kalcounis et al. 1999, Menzel et al. 2000, Hayes and Gruver 2000). Bat activity may decrease with increased altitude, making bat activity levels at the altitude of the turbine blades less than what would be observed on the ground where most activity studies sampled. Gruver (2002) compared bat activity at the top and base of a 15 m tower but concluded there was no significant difference.

The bat activity data gathered thus far at U.S. windfarms indicate that non-migratory bat species are responsible for the majority of activity; yet migratory species make up the greater part of fatalities. Current data suggest bat activity patterns are not consistent over time or space. In addition to these small-scale factors, large-scale factors such as geography must also be considered (Zimmerman and Glanz 2000). All six studies that collected activity data took place in the western or upper midwestern United States. Tennessee Valley Authority’s (TVA) Buffalo Mountain Windfarm (BMW) in eastern Tennessee is the only commercial windfarm operating in the southeastern United States, providing a unique opportunity to add needed information on bat activity and mortality relationships at windfarms, as well as information for the southeastern United States. This study had the following objectives:

1. Determine temporal, spatial, and species-specific patterns of bat activity at BMW using bat detectors;
2. Conduct periodic mist-netting to confirm species presence and compare to acoustical and turbine fatality results;
3. Determine relationships of bat activity patterns with bat mortality.

METHODS

Bat Activity Monitoring

I collected bat activity data with mist-netting and acoustical monitoring. I transformed the number of bat echolocation calls recorded by bat detectors into an activity index as an indicator of overall bat activity. Species-specific activity was determined by using a complement of two methods: quantitatively identifying bat calls recorded by bat detectors and periodic mist-netting (Kuenzi and Morrison 1998, O'Farrell and Gannon 1999).

I passively monitored bat activity with up to four monitoring systems comprised of an Anabat II bat detector (Titley Electronics, Ballina, New South Wales, Australia) which detected ultrasonic frequencies, a zero-crossing analysis interface module (mini-ZCAIM) that transformed ultrasonic sounds into digital computer files, and a laptop computer which digitally stored the computer files. Both the bat detectors and the laptops were powered with one or two 12-volt DC batteries with the exception of one location (top of turbine) where AC power was used. A mini-ZCAIM was powered by some laptops, but otherwise by a 9-volt battery. I set up the monitoring system following O'Farrell (1998). All parts of the system were housed in an 68-liter plastic container with lid and drainage holes, and the bat detector was attached to the opening of curved conduit (6 cm in diameter) that protruded through the container and extended upwards for approximately 20 cm at a 45° angle. Four bat detectors, eight laptops, and six 12-volt batteries were interchanged at up to five locations. Activity monitoring systems recorded continuously until batteries died, and recharged or new batteries were exchanged approximately twice a week.

For accurate comparison of bat activity between locations, it is imperative that different bat detectors have similar sensitivities to bat calls (Barclay 1999, Larson and Hayes 2000). Bat detector sensitivity was standardized using an ultrasonic pest repeller (Sunbeam SC105) (Larson and Hayes 2000) at both the start and middle of both the 2002 and 2003 field seasons. The pest repeller was set directly in front of the bat detectors and the sensitivity dials were set to the lowest sensitivity at which the ultrasonic pulse was still detected at a 15-m distance. I determined inter-detector consistency by recording bat activity simultaneously for two nights (15-16 August 2003) with two monitoring systems set side-by-side and detectors oriented in the same direction over water.

I used Analook software to view and confirm that computer files recorded by the Anabat II monitoring systems contained at least one bat call and discarded all other files. A "bat file" was defined as a computer file containing at least one bat call; a "bat call" was a single echolocation pulse from a bat. A string of calls on the same bat file was defined as a "call sequence" (Figure 9). Bat activity was quantified nightly using an activity index (*AI*), expressed as the percentage of one-minute increments (*m*) containing one or more bat files (*f*) for one complete night of monitoring (adapted from Miller 2001).

$$AI = \left[\frac{f}{m}\right] \times 100\%$$

The length of a night was calculated as the number of minutes from civil dusk to civil dawn of the following morning using time tables on the United States Naval Observatory website (http://aa.usno.navy.mil/, accessed 2003). Although bat activity has been quantified a variety of ways, Miller (2001) found this AI to be an objective and repeatable measure that dispensed with manual definition, identification, and counting of bat calls, passes, or files. AI standardized relative bat activity despite variation in length of night, sequence lengths of different species or bat behavior (e.g., commuting versus foraging, Britzke et al. 1999), and individual abundances and behavior, ultimately allowing for more appropriate spatial and temporal comparisons. Bat AI's were used to describe both temporal and spatial bat activity patterns. All temporal analyses at the seasonal scale used seasonal periods that were selected based on bat biology and included spring migration (1 April to 15 May), summer residency (16 May to 15 July), fall migration (16 July to 30 September); and the period encompassing low or no bat activity and hibernation (1 October – 31 March).

Temporal Patterns of Bat Activity

I determined temporal patterns of bat activity at BMW by monitoring a single reference location near two small, permanent ponds about 75 m from the middle of three wind turbines during the field seasons of 2002 (1 April to 31 October) and 2003 (1 April to 30 September). Intermittent monitoring at this location as part of a pilot project during

2001 (1 April – 31 October) was included for annual analyses only. Bat activity was described at three temporal scales: annual, seasonal, and hourly (over the length of a night).

Spatial Patterns of Bat Activity

Spatial comparisons of bat activity focused on three aspects: presence of water, presence of wind turbines, and altitude. Two locations within 50 m of a wind turbine were used to compare bat activity levels near water (5 m from nearest water) and away from water (150 m from nearest water); these locations were approximately 150 m apart. While keeping presence of water consistent (<5 m), bat activity levels were also compared near wind turbines (50 m) and at two locations away from wind turbines (600 m and 1000 m from nearest wind turbines). Bat activity levels were compared at two different heights: ground and 15 m above ground, and base and top of a wind turbine nacelle (70 m above the ground).

Bat Activity and Mortality Relationships

The relationship between bat activity levels and bat mortality at BMW was explored two ways: on individual nights with known presence or absence of a bat fatality, and also during search intervals used for mortality monitoring (ranging from two to five days) using all bat fatalities. When search intervals were used, I averaged bat AI's over the number of complete nights of acoustic monitoring during the search interval, and categorized a search interval as having or not having a bat fatality occurrence. Although most bat fatalities found were estimated to have occurred since the previous search, a few were estimated to have occurred before the previous search and either placed in the appropriate search interval, or excluded from the analyses. The nightly bat AI's at the reference pond location were used for all bat activity measures, and comparisons were made for 2002 and 2003.

Bat Activity and Weather

AWS Scientific (AWS), a renewable energy consulting company, collected weather data for TVA every ten minutes from a meteorological tower on site at BMW. Parameters were measured at a height of 30 m and included wind speed (m/s), wind direction (degrees), and temperature (°C). TVA personnel calculated an average, a minimum, and a maximum value for each weather parameter during four six-hour periods (2400 – 0600 hours, 0600 – 1200 hours, 1200 – 1800 hours, and 1800 – 2400 hours). The average values from the last six-hour period of one day and the first six-hour period of the next day were used for one night's weather. Electrical generation data for BMW were also collected and processed by AWS. Daily windfarm generation (KW-hours) was recorded at 0800 daily so that one "day" covered an entire night of bat activity. Percent moon face illuminated was calculated using timetables on the Astronomical Applications department website for the U.S. Naval Observatory (http://aa.usno.navy.mil/data/docs/moonfraction.html, accessed June 2002), and were not adjusted for cloud cover.

Nightly averages of wind speed and temperature, and percent moon face illumination were compared to bat activity levels on nights bat AI's were measured at the reference pond location 16 July – 30 September 2002 and 2003. Average nightly wind speed and daily windfarm generation were also compared for these time periods.

Species Identification and Patterns

Bat species present at BMW were identified three ways: visual identification of both turbine fatalities and mist-net captures, and acoustical identification of bat calls. For acoustic identification of bat calls, I used the bat files recorded by the Anabat II monitoring systems. Bat files containing identifiable call sequences were selected using the filter option in the Analook software to remove extraneous material from the bat file (Britzke and Murray 2000). The Analook filter was customized to clean bat files using four parameters: minimum duration of the echolocation call (mindur), minimum sweep or the change in frequency and slope in relation to the characteristic frequency of the call (minsweep), body or the flattest portion of the echolocation call (bodyover), and minimum number of calls in a call sequence (minNcalls) (E. Britzke, pers. comm.).

After application of the filter, parameter values of calls were calculated from the remaining call sequences using Analook software, then saved to a text file. I used a linear discriminant function analysis (DFA) model (Britzke 2003) to assign one of twelve bat species to each call within a sequence based on the extracted parameters. The species included 12 of the 14 species whose ranges include Tennessee (big brown bat, silver-haired bat, red bat, hoary bat, southeastern bat, gray bat, eastern small-footed bat, little brown bat, northern long-eared bat, Indiana bat, evening bat, and eastern pipistrelle) but excluded two uncommon species (Seminole bat and Rafinesque's big-eared bat). Bat sequences were considered positively identified at two thresholds: when > 50% and $\geq$ 75% of the calls within a call sequence were assigned to the same species. The assignment of a species to a call sequence using DFA involves probability, therefore, positive species presence was defined as two or more call sequences identified as the same species during a single night (Britzke et al. 2002). Because gray bat call pulses show a distinctive shape, call sequences identified as gray bats were further analyzed visually (E. Britzke, pers. comm.). Species composition based on acoustical identification was analyzed at the pond reference location for 2002 and 2003, and during seasonal periods.

In addition to acoustical monitoring, periodic mist-netting at the BMW site during 2002 and 2003 was used to both confirm species active in the area and create a comparative composition of species for the acoustical monitoring. Both methods are prone to certain species biases and may not reveal representative species compositions of the area sampled (O'Farrell and Gannon 1999, Murray et al. 1999). I visually identified bats captured with mist-nets following keys in Schwartz and Schwartz (1981). Age was determined using the developmental changes in the cartilaginous growth plates of the fourth metacarpal-phalangeal joint (Anthony 1988); sex was determined by external morphology (Racey 1988). The resulting bat species compositions at BMW study site were compared for both methods, and these results were in turn compared to the species composition of the turbine fatalities.

Statistical Analyses

Temporal bat activity patterns were described at three scales: annual, seasonal, and nightly. Annual bat activity was described by plotting nightly bat AI's over time for all three years. Seasonal bat activity was compared between the three seasonal periods defined by bat biology (spring migration: 1 April – 15 May, summer residency: 16 May – 15 July, and fall migration: 16 July – 30 September). Only nightly AI's from complete nights of monitoring in field seasons 2002 and 2003 were used because 2001 data were not consistently collected over each season. I tested for differences between seasonal bat activity levels using analysis of variance (ANOVA) in PROC MIXED (SAS 2001) with year as a random effect and season as a fixed effect. Patterns of nightly bat activity were described for 2002 and 2003 by plotting the hourly distribution for the critical six-week mortality period, and for the three seasonal periods.

I tested three hypotheses concerning bat activity over a spatial scale: bat activity was greater near water than away from water, bat activity near water did not differ near or away from wind turbines, and bat activity was greater near ground than at turbine blade height. I used paired t-tests (NCSS 2002) to compare bat activity between locations using pairs of AI's recorded only on the same nights; this eliminated confounding effects of weather between nights (Hayes 1997). When necessary I log transformed data (Log + 1) to meet assumptions of normality.

During 16 July – 30 September 2002 and 2003, bat activity levels were compared at two time scales when the presence or absence of bat fatalities was known: individual nights and search intervals. Alternative hypotheses for both time intervals were that bat activity was greater during time intervals containing bat fatalities. Two-sample t-tests were used and data for both time scales were transformed (Log + 1) to satisfy normality assumptions (NCSS 2002). I plotted the average number of bat fatalities found and the average bat activity level (AI from reference location) in a search interval during field seasons 2002 and 2003, and during both years pooled, then used Spearman's correlation to identify the strength of this relationship (NCSS 2002). To determine if bat activity was predictive of bat mortality, I developed a logistic regression model using Proc Logistic (SAS 2001) with presence of a fatality during a search interval as the response variable and bat AI as the independent variable. The probability cutoff in the regression model was chosen to represent a balance between sensitivity and specificity.

Based on scatter plots, I tested for linear correlations between nightly bat activity levels and three biological factors, average nightly wind speed, average nightly temperature, and percent moon face illuminated. I also tested for correlations between average nightly wind speed and daily windfarm generation. Spearman's correlation was used for all comparisons because the bat AI variable failed tests of normality (PROC CORR, SAS 2001). Species compositions of turbine fatalities and acoustical recordings were compared using Fisher's Exact Test (PROC FREQ, SAS 2001).

RESULTS

Detector Accuracy

During a test of recording accuracy, detector A recorded 255 bat files and detector B recorded 264 bat files over two complete nights of monitoring. The two-night AI was 15.51 and 15.87 for detectors A and B, respectively, with a difference of 0.36. Of the bat files recorded by both detectors, 233 were determined to be the same based on the date-time information encoded into each computer file name. Detector A recorded 21 bat files that B did not and detector B recorded 31 bat files that A did not. Those 52 additional bat files would have increased the number of 233 similar bat files to a total of 285 (22.3% increase), and the bat AI would have increased from 14.31 to 17.03 (19.0% increase). For detectors A and B, 25 and 36 bat files were of sufficient quality to be identified using acoustical identification model. Eighteen were files recorded simultaneously by both the detectors. Of these 18, three (16.7%) were assigned to different species. Call parameter values extracted from two files recorded by detector A were identified as silver-haired bat, but simultaneously recorded files from detector B produced call parameter values consistent with big brown bat. Also, a call sequence recorded by detector A was identified as evening bat, but call parameter values from a file recorded simultaneously by detector B was identified as red bat.

Temporal Patterns of Bat Activity

Of 586 possible recording nights between 26 April 2001 and 30 September 2003, 259 (44.2%) were monitored for the entire night (2001: n = 50, 2002: n = 126, 2003: n = 83); AI's were calculated for all complete nights of monitoring (Appendix C). Based on scatter plots of bat activity over the course of the field season for 2001 through 2003, annual bat activity levels were consistently greater during late summer and early fall (Figure 10). Data from 2002 showed an increase starting in mid-July, peaking in mid-August, and declining into late September. A similar pattern developed during 2003 with a peak in mid-August, but bat activity levels started increasing later (beginning of August) and declined earlier (beginning of September). Although few data were collected during the time of peak activity during the 2001 pilot study, the few points collected imply a peak from late July to mid-September.

The late summer / early fall peak in bat activity levels was confirmed with seasonal analyses for 2002 and 2003. Bat activity differed among the three seasonal periods (F = 35.94, P = 0.03), and there was no interaction between year and season (F = 0.01, P = 0.94). Multiple comparison tests (LSD) further revealed that Jul – Sep AI was greater than Apr – May AI, but May - Jul AI did not differ from Jul – Sep AI or Apr – May AI (Table 21 and Figure 11).

Plots of nightly bat activity consistently showed an initial increase in activity at dusk and decrease prior to dawn during all seasons for both 2002 (Figure 12) and 2003 (Figures 13). The Jul - Sep period had greater nightly activity than either the Apr - May or May - Jul seasonal periods, and therefore patterns appeared magnified. Data from 2002 exhibited a distinct bimodal pattern while 2003 lacked the lull in activity during the middle of the night and showed relatively consistent activity throughout the night. Although the Apr - May and May - Jul activity levels were much reduced compared to Jul - Sep for both years, data from 2002 revealed a slight bimodal pattern during May - Jul and a single initial peak of activity just after dusk during Apr - May. Data from Apr - May and May – Jul 2003, however, were similar to Jul – Sep 2003 and exhibited a relatively consistent activity pattern throughout the night hours.

Spatial Patterns of Bat Activity

Within the BMW site, bat activity near water (5 m) was greater than bat activity away from water (150 m) for 77 nights during 2002 and 2003 ($t = 11.21$, $P < 0.0001$; Table 22). When the presence of water was held constant, bat activity onsite differed with two areas offsite, away from wind turbines (Table 22). The first offsite area had greater bat activity when paired with onsite monitoring for 37 nights during 2002 and 2003 ($t = 4.22$, $P = 0.0002$), and the second offsite area had lesser bat activity when similarly paired with onsite monitoring for 22 nights in 2002 ($t = -4.65$, $P = 0.0001$).

Bat activity did not differ between a ground-based bat detector and a detector located 15 m higher for 13 nights during summer 2002 ($t = 0.66$, $P = 0.26$, Table 23). However, bat activity at the base of a wind turbine was greater than bat activity on top of a wind turbine nacelle (70 m) for 28 nights during Aug - Oct 2002 ($t = 7.37$, $P < 0.0001$)

and nine nights in summer 2003 ($t = 2.46$, $P = 0.02$; Table 23). Monitoring systems on top of the wind turbine nacelle generally recorded more interference files than ground-level systems. However, the interference events were not consistent enough to attribute to blade rotation or other turbine functions and most likely resulted from greater exposure to weather.

Bat Activity and Mortality Relationships

On individual nights using only fresh fatalities, bat activity levels were greater during nights containing bat fatalities than bat activity levels on nights without fatalities ($t = 2.54$, $P = 0.0067$). A difference was not found in bat activity levels when the time interval was expanded from individual nights to search intervals and all fatalities were used ($t = -1.05$, $P = 0.15$), although low power ($ß = 0.09$) may have precluded a true difference from being found (Table 24). Correlations indicating the strength of the relationship between average number of fatalities found and average bat activity (AI) during search intervals were positive for field seasons in 2002 ($r = 0.49$, $n = 48$, $P = 0.0004$, Figure 14), 2003 ($r = 0.45$, $n = 38$, $P = 0.0050$, Figure 15), and both years combined ($r = 0.47$, $n = 86$, $P < 0.0001$). The logistic regression model of bat fatality occurrence using AI as an explanatory variable performed poorly (Wald χ^2 $P = 0.22$, max rescaled $r^2 = 0.05$, correct classification = 66%) when AI was averaged across search intervals using all bat fatalities, but performed better when individual nights with fresh fatalities were used (Wald χ^2 $P = 0.02$, max rescaled $r^2 = 0.15$, correct classification = 58%). A probability cutoff of 0.50 was chosen for the model using search intervals, represented a balance between sensitivity (60.0%) and specificity (55.6%). For the model using individual nights, a balance between sensitivity (62.5%) and specificity (66.7%) was reached at a probability cutoff of 0.10.

Bat Activity and Weather

During the Jul – Sep seasonal period, bat activity showed a positive relationship with average nightly temperature ($r = 0.60$, $n = 99$, $P < 0.0001$, Figure 16), a negative relationship with average nightly wind speed ($r = -0.31$, $n = 99$, $P = 0.0020$, Figure 17) and no relationship with percent moon face illuminated ($r = -0.02$, $n = 99$, $P = 0.8174$, Figure 18). Amount of daily electrical generation at BMW had a positive correlation with wind speed ($r = 0.62$, $n = 99$, $P < 0.0001$, Figure 19) and a negative correlation with bat activity ($r = -0.21$, $P = 0.04$, Figure 20).

Species Identification and Patterns

Ten out of the 12 possible bat species available in the DFA model were identified from bat files recorded at BMW. When positive species identification of a call sequence was defined as greater than 50% of the pulses within a call sequence identified to the same species, 2,081 of 14,462 bat files (14.4%) from the reference location were positively identified (2002 = 1,549; 2003 = 532). At a 75% confidence threshold 1,517 bat files (10.5%) were positively identified (2002 = 1,107; 2003 = 410). Because the majority of the identifiable calls were retained (73%) when the confidence threshold increased from 50% to 75%, only data based on the 75% confidence threshold were used for the remaining species identification analyses. Three of the ten species identified acoustically never had more than one call in a single night (little brown bat, Indiana bat, and northern long-eared bat), therefore presence of these species was not confirmed. All but one call sequence initially identified as gray bat by the DFA model lacked the pulse shape distinctive to gray bats (E. Britzke, pers. comm.). Because no species had a prediction accuracy of 100% for this DFA model, more than one positively identified call per night was needed to confirm presence (Britzke et al. 2002, Britzke 2003), therefore gray bats were not confirmed at the BMW site. Of the remaining six species, three were identified on greater than 10% of the monitored nights: eastern pipistrelle (33.8%), big brown bat (14.2%), and red bat (10.9%; Table 25). Three additional species, silver-haired bat, hoary bat, and evening bat were considered present during less than 10% of the monitored nights (Table 25).

Among the six bat species considered present at BMW based on acoustical identification, four were considered present during the Apr – May period, five were present during May – Jul, and all six were present during Jul – Sep (Table 26, Figure 21). Silver-haired bats and hoary bats were present more commonly during monitored nights in Apr - May, and the remaining four bats: eastern pipistrelle, big brown bat, red bat, and evening bat were present most often during the Jul - Sep period, with the evening bat being present only during Jul - Sep.

A total of 49 bats of five species were captured at three locations on or near the windfarm during 14 nights in 2002 (n = 38 bats) and 4 nights in 2003 (n = 11 bats, Table 27). Red bats were most common (n = 35) followed by eastern pipistrelle (n = 5), northern long-eared bat (n = 4), big brown bat (n = 3), and hoary bat (n = 2). More males were captured than females (n = 43 and 6, respectively) and more adults than juveniles (n = 31 and 18, respectively). The first juveniles were captured on 31 July 2002 and 19 August 2003.

During 2002 and 2003, six bat species were identified acoustically and considered present at BMW site after 209 nights of monitoring. Only four of those species, along with one additional species (northern long-eared bat) were captured during mist-netting on 18 nights in 2002 and 2003 (Table 27). The two species identified through acoustical monitoring but not captured by mist-netting were evening bat and silver-haired bat.

Six species were found among the turbine fatalities and four of those were identified with both mist-netting and acoustical monitoring (red bat, eastern pipistrelle, hoary bat, and big brown bat; Table 28). Silver-haired bat was identified with acoustical monitoring but not captured during mist-netting. The sixth species, Seminole bat, was unexpected since this species has not been previously recorded in Tennessee north of Monroe County (Kennedy et al. 1984). Not surprisingly, this species was not captured during mist-netting, nor identified acoustically as it was unavailable as an option for the acoustical identification model. Because of the limited sampling with mist-netting, species composition comparisons with turbine fatalities could realistically only be made using acoustical monitoring results. Using the two years with sufficient acoustical monitoring (2002 and 2003), comparisons were made during the Jul / Sep period that contained the majority of fatalities, and species compositions of turbine fatalities and acoustical recordings were different ($P = 0.008$). Three species were found as turbine fatalities proportionally less than were acoustically recorded (eastern pipistrelle bat, big brown bat, and silver-haired bat) and two species were found proportionally more (red bat and hoary bat; Figure 25).

DISCUSSION

Bat Activity and Mortality Relationships

Bat mortality at BMW was correlated with acoustically measured bat activity levels, but differences in bat activity levels during time intervals with and without mortality depended on temporal resolution. Differences in activity levels were significant when individual nights were used rather than search intervals. The number of individual nights however, was limited by both the small number of bat fatalities found fresh enough to be confidently assigned to a particular night, and the number of corresponding nights bat activity was successfully monitored. When the temporal resolution was extended from individual nights to search interval (2-5 days), information related to all bat fatalities could be used, but averaging reduced precision and comparisons subsequently lacked significance. Temporal resolution also affected the ability of logistic regression models to predict bat fatality events using bat activity levels. Despite the better performance of the model using individual nights, the low probability cutoff (0.10) indicates that it was difficult for this model to predict fatality events – most likely because of the few fresh fatalities that were used to build the model. One explanation for the influence of the temporal resolution could be the great variability in bat activity between nights (Hayes 1997). Despite the limitations imposed by the temporal resolution, bat mortality was positively related to bat activity levels at BMW, although activity predicted only a small portion of the variance associated with the likelihood of mortality.

The only other study relating bat mortality and activity was at Buffalo Ridge WRA, MN, but they measured the relationship spatially rather than temporally by comparing bat activity at turbines where fatalities did and did not occur (Johnson et al. 2003a). However, using acoustical monitoring, the MN study found a peak in bat activity (mid-July to mid-August) that corresponded with the peak in mortality (mid-July to last August; Johnson et al. 2003a). Therefore, both temporal and spatial resolutions need to be considered when evaluating bat activity and mortality relationships at windfarms. The bat activity-mortality relationship noted at BMW indicates the further importance of understanding the temporal and spatial patterns of bat activity before appropriate predictions of bat mortality can be made.

Temporal Bat Activity Patterns

The basis for the bat activity - mortality relationship was the peak in bat activity levels observed during late summer / early fall for all three years of this study (Figure 10). Potential reasons for this peak in activity include increased number of volant juveniles, onset of bat breeding season, and/or fall dispersal and migration. Again, the Buffalo Ridge WRA, MN was the only other windfarm that considered annual temporal changes in bat activity levels based on acoustic monitoring, and reported an increase from mid-July to mid-August (Johnson et al. 2003a). The length of the bat activity peaks at BMW differed between 2002 and 2003, but the peaks were during mid-August for both years – a few weeks later than at the Buffalo Ridge WRA, MN. The more northerly location of the MN wind project logically explains the earlier onset of breeding and migration activity.

At a finer temporal scale, hourly bat activity at BMW was bimodal during nights in 2002, but relatively consistent throughout nights in 2003. Erkert (1982) suggested that bimodal activity is characteristic of all insectivorous bats studied so far. This bimodal pattern may be the result of two foraging periods interrupted with night roosting (Anthony et al. 1981), a pattern especially apparent during lactation for female bats returning to maternity roosts to feed young (Swift 1980, Maier 1992). Fluctuation in insect abundance, shown to follow bimodal patterns (Swift 1980), may also drive bimodal patterns of nightly bat activity (e.g., Racey and Swift 1985, de Jong and Ahlen 1991). The unimodal pattern during 2003 may be related to the overall decreased bat activity observed that year compared to 2002. Erkert (1982) postulated that insectivorous bats would be unlikely to show the usual bimodal pattern if low prey densities forced continuous foraging. Changes in insect abundance and/or unusually cold or inclement weather may also influence the normal bimodal patterns observed in bats. Wetter and cooler weather conditions were reported during the summer and fall of 2003 than during 2002 for Oak Ridge, TN, five miles south of BMW (National Climatic Data Center 2002-2003).

Spatial Bat Activity Patterns

Bat activity levels varied spatially as well as temporally. Water concentrates bat activity (e.g., Walsh and Harris 1996, Vaughan et al. 1997) because of 1) the water available for necessary drinking, and 2) the increased insect abundances near water (de Jong and Ahlen 1991). Bat activity was greater near water at BMW than activity at a site 150 m away from water. However, activity levels also varied between three sites near water. The water site with the greatest bat activity at BMW was a large, semi-permanent puddle, situated in the middle of a narrow dirt road cutting through trees and scrubby vegetation along a ridgeline. This dirt road may have served as a corridor for bats commuting to and from foraging and roosting areas. Greater bat use of corridors has been shown in some studies (de Jong 1995) but not in others (Law et al. 1999) and is likely dependent on additional habitat or species factors. The water site experiencing the next greatest bat activity was a semi-permanent pond, significantly larger, containing well-developed emergent and submergent aquatic vegetation, but in more open habitat than the other two water sites. This site was also nearest the wind turbines (within 100 m) whereas the other two sites were 400 and 1000 m away from the closest wind turbines. The size and proximity of a water feature, the surrounding habitat configuration, and the possible aversion of bats to nearby turbine blades, may have all been factors contributing to significant differences in bat activity at the three water sites. These are all factors that should be controlled if attempting to tease apart the amount of influence any one factor has on bat activity.

Other windfarms have also considered spatial differences in bat activity, recognizing landscape context and habitat features as possibly important elements in avoiding future bat mortalities (Erickson et al. 2002, Gruver 2002, Johnson et al. 2003a, Schmidt et al. 2003). If a positive correlation between ground-level bat activity and bat mortality at wind turbines is found, the presence of features attracting greater concentrations of bat activity, such as water or roosting structures, may be important criteria when selecting sites for future windfarms.

One spatial feature easily overlooked is altitude. This is an especially relevant issue at windfarms because bat activity can be most easily measured at ground level, but mortality occurs at blade height, well beyond the range of most bat detection methods (i.e., mist-netting and bat detectors). At BMW, a height of 15 m was not enough to show a difference in bat activity measured with acoustical methods – but there was a difference at 70 m (blade hub height). Bat activity levels were significantly lower at blade hub height than at ground level during the heavy activity period of Jul – Sep (2002) and also during the lower activity period May – Jul (2003). It is important to note, however, that the bat activity measured at 70 m was taken from the top of a wind turbine and measured the exact air space of interest, but this made it impossible to separate the effect of bats possibly avoiding the actual blades from that of height.

Lower bat activity at greater heights above ground may be attributed to two factors 1) morphological constraints of some species, and 2) lower insect prey abundances. Bat activity levels and species assemblages vary by vertical strata in several different forest types (Bradshaw 1996, Lance et al. 1996, Kalcounis et al. 1999, Hayes and Gruver 2000, Menzel et al. 2000). The difference in species assemblages is commonly attributed to morphological differences that limit flight style and maneuverability of structural clutter (Norberg and Rayner 1987). Morphological constraints may limit species able to utilize large, open-air spaces (e.g., at blade height) because of increased wind strength. This includes species within the *Myotis* genus, whose average to low wing loading and low aspect ratio, predicts slow but agile flight (Norberg and Rayner 1987). In contrast, the flight styles of the hoary bat and red bat are consistent with morphological measures that predict fast flight and less maneuverability (Norberg and Rayner 1987), making these two species more likely to occur at blade height. Just as large, open-air spaces with wind may affect bat use, it may also reduce insect abundances, which in turn may reduce bat activity (de Jong and Ahlen 1991, Hayes 1997). Brazilian free-tailed bats (*Tadarida brasiliensis*), however, have been recorded foraging as high as 1500 m foraging on migrating corn earworms (*Helicoverpa zea*)

(McCracken et al. 1996 and 1997). The disparity in bat activity at different altitudes becomes relevant when activity measured at ground level is used to infer activity at blade height, and indirectly, bat mortality at windfarms. If an exact relationship between bat activity and height is understood, then ground measures could reliably be used for predictions.

Bat Activity Associations with Environmental Factors

An association between bat activity and mortality has been established at BMW, and factors influencing bat activity may be helpful in both determining mitigation criteria and elucidating underlying causes of bat mortality. Bat activity at BMW was most closely correlated with average nightly temperature. Positive correlations of bat activity and temperatures are common in bat literature, both over an annual time period (O'Farrell and Bradley 1970, Avery 1985, Rydell 1991), and on a nightly basis (Lacki 1984, Negraeff and Brigham 1995, Hayes 1997, Vaughan et al. 1997, Gaisler et al. 1998, Shiel and Fairley 1998). Bat activity levels at BMW also showed a negative association with average nightly wind speed. The association of bat activity with wind speed is less commonly reported (Adam et al. 1994, Russo and Jones 2003), but is intuitive because the flight ability of bats, as relatively small, volant mammals, is limited by wind strength, as are their airborne, insect prey. Bat activity was also negatively associated with amount of windfarm generation at BMW. This is most likely an indirect relationship because as wind increases, windfarm generation will increase, but bat activity will decrease because wind strength, not generating wind turbines, will inhibit flight. The percent moon face illuminated was a third environmental factor tested for an association with bat activity at BMW; no relationship was found although cloud cover was not considered and may have obscured a relationship. Negraeff and Brigham (1995) hypothesized that insectivorous bat activity may be lower on brighter nights because of either greater predation risk or lower insect abundances that may also be responding to increased predation risk. However, neither their study nor subsequent studies have found a lunar effect of bat activity levels (Gaisler et al. 1998, Hayes 1997, Parsons et al. 2003, Russo and Jones 2003). Although no lunar effect on bat activity levels has been established, habitat shifts in response to moonlight have been demonstrated (Reith 1982, Adam et al. 1994, Hecker and Brigham 1999, but see Negraeff and Brigham 1995, Brigham et al. 1997).

Species Identification

Although overall activity levels provide some basic information on bat activity at BMW, activity information on individual species may better elucidate relationships between bat activity and mortality at windfarms. Species-specific activity at BMW was evaluated using both acoustic monitoring with bat detectors and mist-netting captures. With acoustical monitoring, I was able to sample BMW over a much more comprehensive time period than with mist-netting and identified six species (red bat, eastern pipistrelle, big brown bat, hoary bat, silver-haired bat, and evening bat), compared to five species with mist-netting (red bat, eastern pipistrelle, big brown bat, hoary bat, and northern long-eared bat); four species were similar among methods (Table 28). Both methods have inherent benefits and biases when determining species diversity or activity levels, but together are considered complementary methods (Kuenzi and Morrison 1998, O'Farrell and Gannon 1999). Two species (evening bat and silver-haired bat) were detected with acoustical monitoring but not mist-netting. As with this study, acoustical monitoring often enables more comprehensive sampling over time and space, because multiple detectors can record passively in many areas that cannot be logistically mist-netted. However, bat detectors are biased towards species with lower echolocation frequencies that carry further, and tend to underestimate species emitting higher, weaker frequencies (Griffin 1971). This bias may explain why the northern long-eared bat, known to have an echolocation call of weak intensity, was not detected by acoustical techniques but was in the mist-net sample. Weak calls not only attenuate more rapidly through the air, but also attenuate each time they bounce on a surface such as the curved conduit connected to the receiving end of the bat detector (E. Britzke, pers. comm.).

Despite the more stringent logistics of mist-netting, direct capture techniques allow for visual confirmation of species. Acoustical species identification, however, incorporates many different sources of variation, all of which reduce the probability that a call sequence will be correctly identified (Barclay 1999). These sources of variation include detector brand (Fenton 2000), individual detectors (Larson and Hayes 2000), and attenuation of calls in different habitats (Griffin 1971, Brigham et al. 1997, Patriquin 2003). Species identification is further complicated by call structures varying with geographic region (Thomas et al. 1987, O'Farrell et al. 2000, Murray et al. 2001), gender (Jones et al. 1992), and age (Jones and Ransome 1993, Kazial et al. 2001). High intraspecific variation, especially among red bats, is conducive to overlapping of parameters with other species – again increasing the risk of inaccurate identification and possibly explaining part of the disparity between the low proportions of red bats at BMW detected acoustically compared to mist-netting (E. Britzke, pers. comm.). Despite the confidence given from visual examination of mist-net captures, mist-netting as a technique also has biases. Species that tend to fly outside of the spatial sampling range of mist-nets (e.g., higher, or in dense vegetation) tend to be underrepresented. The detection of silver-haired bats with acoustical monitoring but not mist-netting may be a result of this bias.

Bat Species Composition

Both acoustical monitoring and mist-netting surveys provided information on species diversity and abundance at BMW. Resulting species composition of active bats contrasted with that of turbine fatalities at BMW, indicating differential risks for bat species. Two species were detected with the activity survey methods that were not found among the fatalities (northern long-eared with mist-netting, and evening bat with acoustical monitoring), although both were infrequently detected. *Myotis* species were also detected with activity studies more often than were found among turbine fatalities at two other windfarms. Gruver (2002) found only 6 (4.9%) turbine fatalities at Foote Creek Rim wind plant, WY were a species of *Myotis* (little brown bat), while at least three *Myotis* species composed 80.8% of mist-net captures and 79.2% of acoustically recorded bat calls. Buffalo Ridge WRA, MN also had a lower proportion of little brown bats (1.9%) among turbine fatalities than found in mist-netting surveys (10.7%; Johnson et al. 2003a). Although comparable activity studies have not been conducted, mortality studies from ten other windfarms reported only 17 turbine fatalities (2.2%) of one *Myotis* species, the little brown bat (Johnson et al. 2003a, Erickson et al. 2003b). While *Myotis* species seem at low risk for turbine collisions at most windfarms, recent preliminary findings at Mountaineer Wind Energy Center, WV included two species of *Myotis* fatalities - 60 fatalities of little brown bat and six of northern long-eared bat, together making up 13.9% of total turbine fatalities (Kerns and Kerlinger 2004). Although the

West Virginia windfarm is the most comparable windfarm to BMW in many ways, no *Myotis* species were found at BMW. Considering the scarcity of *Myotis* species detected during activity studies at BMW, the lack of *Myotis* fatalities at BMW was probably a reflection of low *Myotis* abundances at the site.

In contrast, collision risk was greater for two *Lasiurus* species, the red bat and hoary bat. Turbine collisions of these two species were disproportionately greater than acoustical monitoring indicated at BMW. The widespread ranges of these two species, along with their ability to migrate relatively long distances (Barbour and Davis 1969) are probably two contributing factors. These two species were also the two most common turbine fatalities at ten other windfarms (Johnson et al. 2003a, Erickson et al. 2003b, Kerns and Kerlinger 2004). Comparable activity studies were conducted at two windfarms. *Lasiurus* species made up 7.8% of mist-net captures at Buffalo Ridge WRA, MN while the same group made up 82.4% of the turbine fatalities (Johnson et al. 2003a). Although the eastern red bat does not occur at the Foote Creek Rim wind plant, WY, the hoary bat does and accounted for 87.8% of the turbine fatalities (Gruver 2002). During activity monitoring, Gruver detected an order of magnitude fewer hoary bats during both acoustical monitoring (7.8%) and mist-net captures (6.5%). A lone specimen of a third *Lasiurus* species, Seminole bat, was also found at BMW. The range of this species however, is well south and east of all other windfarms (Barbour and Davis 1969) and is probably only a vagrant at BMW site.

Eastern pipistrelle, big brown bat, and silver-haired bat were all detected acoustically more than observed among turbine fatalities at BMW. The latter two species are sometimes placed in a species complex for acoustical identification because of similar call parameters (Gannon et al. 2003, E. Britzke, pers. comm.). Whether separated or combined, both species appeared to be active on site, but were at a reduced risk for turbine collision. Activity studies at both Foote Creek Rim wind plant, WY and Buffalo Ridge WRA, MN also found greater proportions of active bats for these two species then were found among the turbine fatalities (Gruver 2002, Johnson et al. 2003a).

Turbine collision risk also appeared proportionally less for eastern pipistrelle, although the large number of fatalities at BMW was surprising considering how rarely they were found at most other windfarms. Of mortality results from ten windfarms, Johnson et al. (2003a) reported only Buffalo Ridge WRA, MN as having eastern pipistrelle among the turbine fatalities, but at a much lower percent (1.7%; Johnson et al. 2003a) than at BMW (24.6%). Because eastern pipistrelle made up the majority of the acoustical recordings at BMW, and the species range only overlaps three eastern windfarms [Barbour and Davis (1969) reported by Johnson et al. (2003a)], regional abundance seems the best explanation for the large proportion of eastern pipistrelle turbine fatalities at BMW compared to other windfarms. Recent preliminary findings at Mountaineer Wind Energy Center, WV supported this explanation, where a total of 87 eastern pipistrelles (18.3%) were found among turbine fatalities in 2003.

Several factors seem at work in determining the species composition of bat fatalities at windfarms. Species range is important in that some species are less available, or not at all, to collide with turbines in different regions of the country. The greater proportion of eastern pipistrelles at the two windfarms within the core of this species' range (BMW and Mountaineer Wind Energy Center, WV) is one example. The lone Seminole bat fatality at BMW, the only windfarm even close to the range of this species, is another example. Migratory status is a second important factor, as in the case of the red bat and hoary bat, currently the two most common fatalities at windfarms. Non-migratory bats appear less at risk (e.g., big brown bat), as well as any bat outside the late summer / early fall mortality window. Although *Myotis* species seem less at risk for turbine collisions than *Lasiurus* species, two endangered *Myotis* species in the East, gray bat and Indiana bat, undertake regional migrations that could possibly increase their risk for turbine collisions at a smaller, more localized scale.

V. SYNTHESIS OF BAT MORTALITY AND ACTIVITY AT BUFFALO MOUNTAIN WINDFARM

Based on the three-year study at BMW, an adjusted bat mortality rate of 20.82 bats / turbine / year was estimated for this windfarm. This rate is many times greater than mortality rate estimates at ten other windfarms (range: 0.1 – 4.3 bats / turbine / year, Johnson et al. 2003a, Erickson et al. 2003b), but less than half of the preliminary mortality rate reported at the Mountaineer Wind Energy Center, WV (47.5 bats / turbine for 2003, Kerns and Kerlinger 2004). The Mountaineer Wind Energy Center is the closest windfarm to BMW, and the only other windfarm situated along a forested, prominent ridgeline, rather than the flatter, more open land of most other windfarms in the western and midwestern United States. The similarities of landscape or region seems tied to the unusually high bat mortality rates at both windfarms, and may have important implications for future windfarms in the eastern United States.

Differences in mortality rates may reflect variation in carcass search protocols and / or frequencies between windfarms, as well as in determination of search biases used to adjust observed mortality rates (Morrison 2002). Several biases affect estimates of bat mortality rates at windfarms: searcher efficiency, scavenging rates, search interval, background mortality rates, crippling bias, plot size, and seasonal vegetation cover. It is important for individual windfarms to estimate these biases when calculating mortality rates, as both regional and site-specific conditions can influence them.

Regional variation in bat species abundances and diversity may provide some explanation for the differences in mortality rates between windfarms, but activity studies are needed in conjunction with mortality studies to provide an appropriate context.

Activity studies using bat detectors at BMW identified two species that were active proportionally less than turbine fatality results indicated (red bat and hoary bat), but three were identified as active at greater proportions than were found among fatalities (eastern pipistrelle, big brown bat, and silver-haired bat). This result supports the hypothesis that some species have an increased risk for turbine collisions. Mist-net efforts captured an additional species not among the fatalities or detected with acoustical monitoring (northern long-eared bat), and neither mist-netting nor acoustical methods detected the presence of the Seminole bat, a species whose range is predominantly south of BMW but was represented by a single fatality at BMW. Because both methods identified additional species not otherwise detected at BMW (northern long-eared bat with mist-netting, and evening bat with acoustical identification), and both acoustic and direct capture methods have biases, a complement of acoustic and direct capture methods may best assess bat species active in an area (O'Farrell and Gannon 1999, Murray et al. 1999). It is also important to understand and state method biases and assumptions when reporting and reporting results (Gannon et al. 2003).

Six species of bat fatalities were found at BMW, but 96% consisted of only three species (red bat, eastern pipistrelle, and hoary bat). Red and hoary bats, in addition to silver-haired bat, were the most common species found among bat fatalities at other windfarms (Johnson et al. 2003a). These latter three species have widespread ranges and are known to migrate long distances, two factors that may contribute to their increased exposure to turbine collisions. The lack of many silver-haired bats among BMW fatalities is most likely a reflection of the scarcity of this species in the Southeast compared to the rest of the country. The greater proportion of eastern pipistrelles at

BMW compared to most other windfarms is probably also related to the species range; the eastern pipistrelle encompasses only the eastern United States and is absent from the regions containing the majority of the windfarms reporting mortality results. Similar proportions of eastern pipistrelle fatalities were found at Mountaineer Wind Energy Center, WV, the closest windfarm to BMW. Range may also be the explanation for the sole Seminole bat fatality at BMW, the only windfarm even close to the strictly southeastern range of this species. Non-migratory bats (e.g., big brown bat) appear less at risk, as well as any bat outside the late summer / early fall mortality window. Although *Myotis* species seem less at risk for turbine collisions than *Lasiurus* species based on results at BMW, two endangered *Myotis* species in the East, gray bat and Indiana bat, are regional migrants. Future windfarm development within the range of these species should consider whether these species might experience increased risk for turbine collisions.

A seasonal peak in bat mortality was established at BMW with 70% of fatalities occurring between the beginning of August and mid-September; consistent with mortality peaks at other windfarms. A temporal concentration such as this allows possible mitigation measures in the form of locking down turbines during high-risk times. Interestingly, the mortality peak at BMW coincided with the lowest annual wind period, when only 5.6% of the annual windfarm generation occurred. If similar wind profiles exist at other windfarms, this occurrence may provide an opportunity for mitigation at current and future windfarms. The effectiveness of this type of mitigation may further increase if indicators can predict smaller periods of high-risk bat mortality, such as specific nights, or portions of nights. Possible indicators include bat activity levels and weather conditions, but further research is needed to resolve these specific relationships.

Bat activity levels (AI) at BMW were correlated with bat fatality events when averaged over search intervals during 2002 and 2003 combined ($r = 0.47$, $P < 0.0001$), but the ability of bat AI to predict the likelihood of mortality depended on temporal resolution. Also, four weather variables were associated with bat fatality events at BMW (average nightly wind speed (-), wind speed difference (-), average nightly wind direction (+), and maximum temperature (-), Table 12). Complicating matters, bat carcasses were backdated to 37% of the nights during the six-week mortality peak, indicating that season may be a more reliable predictor of fatality occurrence than conditions of specific nights. If predictive indicators such as bat activity and weather conditions are to be employed, appropriate temporal resolution should be used and proper associations should be made. For example, if certain environmental variables such as temperature are associated with bat activity levels, and a relationship between bat activity levels and bat mortality is established, a relationship between temperature and occurrence of bat mortality cannot be automatically extrapolated. Another example is nightly activity patterns; bimodal patterns of nightly activity are commonly reported for insectivorous bats (Erkert 1982), but variation in these patterns (nightly activity patterns at BMW were bimodal in 2002 but unimodal in 2003) may make this an unreliable predictor for portions of nights when fatalities may occur. Therefore, it is critical that appropriate associations be established for individual windfarms at a local scale.

Elucidating the mechanism behind bat mortality at windfarms will also facilitate possible mitigation measures. Migration has become the most probable risk characteristic based on seasonal timing and species of turbine fatalities. However, it is not known if bats are colliding with wind turbines while actually migrating or during other activities (i.e., foraging or breeding activities) that occur during migration. The lack of correlations between nightly windfarm generation at BMW and the degree of injury sustained by a bat initially casts doubt on whether bat are being struck by turbine blades or running into the turbines themselves. However, blades still spin at low winds without generating electricity and degree of injury, in addition, degree of injury may not be a good measure because only external injuries were assessed. A better understanding of why bats are colliding with turbines is needed. Methods that will allow visual observation of bat movement around turbine blades, such as radar, may be the next step in understanding the issue of bat mortality at windfarms.

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APPENDICES

APPENDIX A

FIGURES

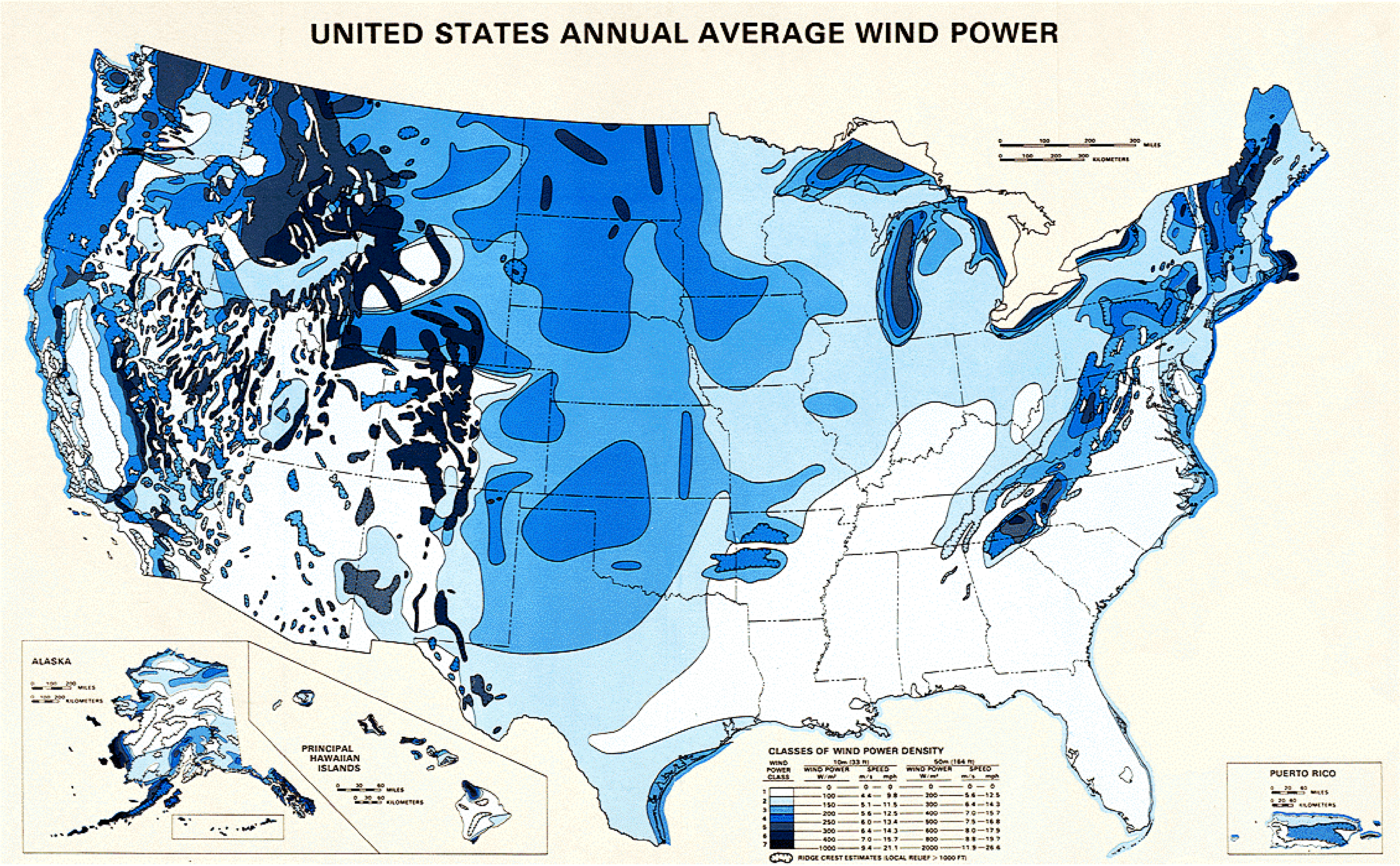


Figure 1. Distribution of annual average wind power as presented by Elliott et al. 1986 in the "Wind Energy Resource Atlas of the United States" a document prepared by Pacific Northwest Laboratory for the U.S. Department of Energy.

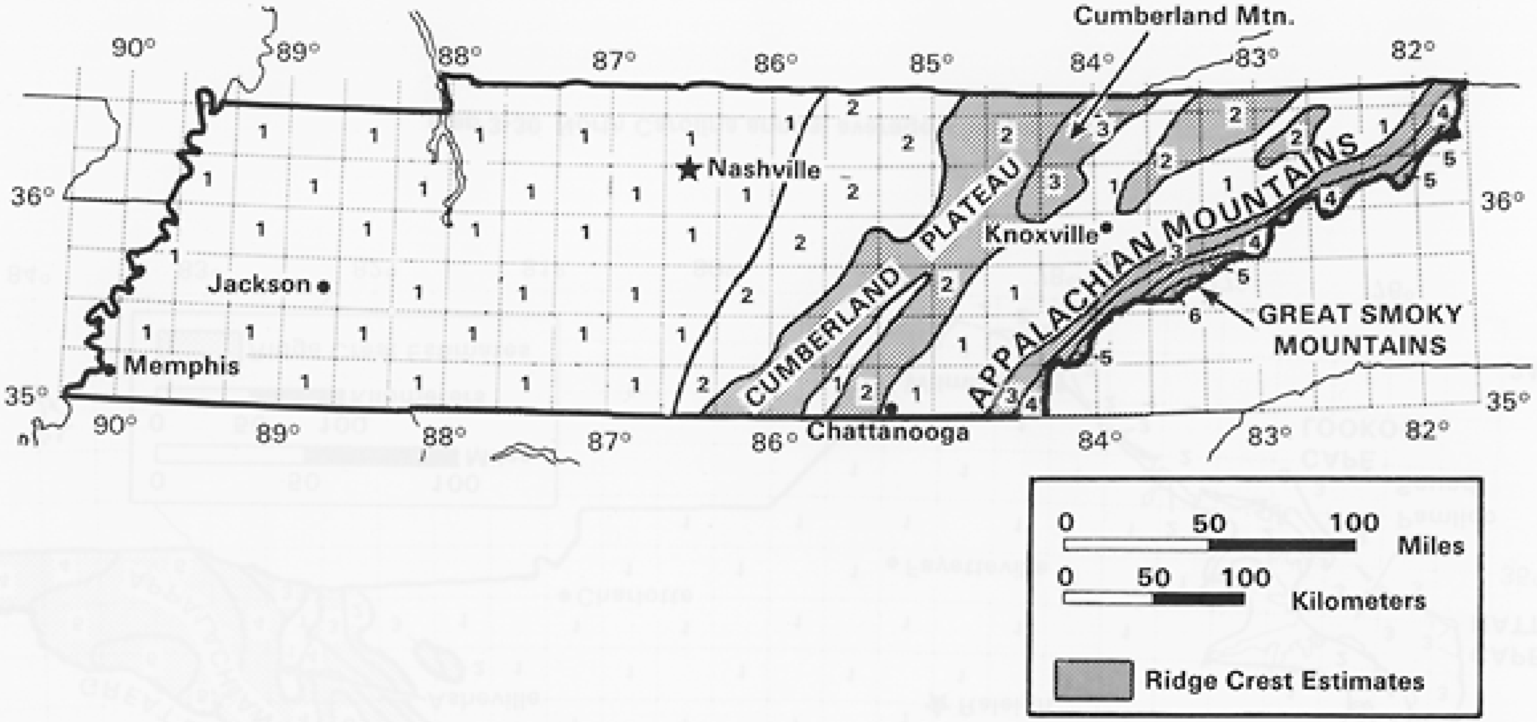


Figure 2. Distribution of wind power potential for the state of Tennessee as presented by Elliott et al. 1986 in the Wind Energy Resource Atlas of the United States, a document prepared by Pacific Northwest Laboratory for the U.S. Department of Energy. Wind power potential increases with numbers.

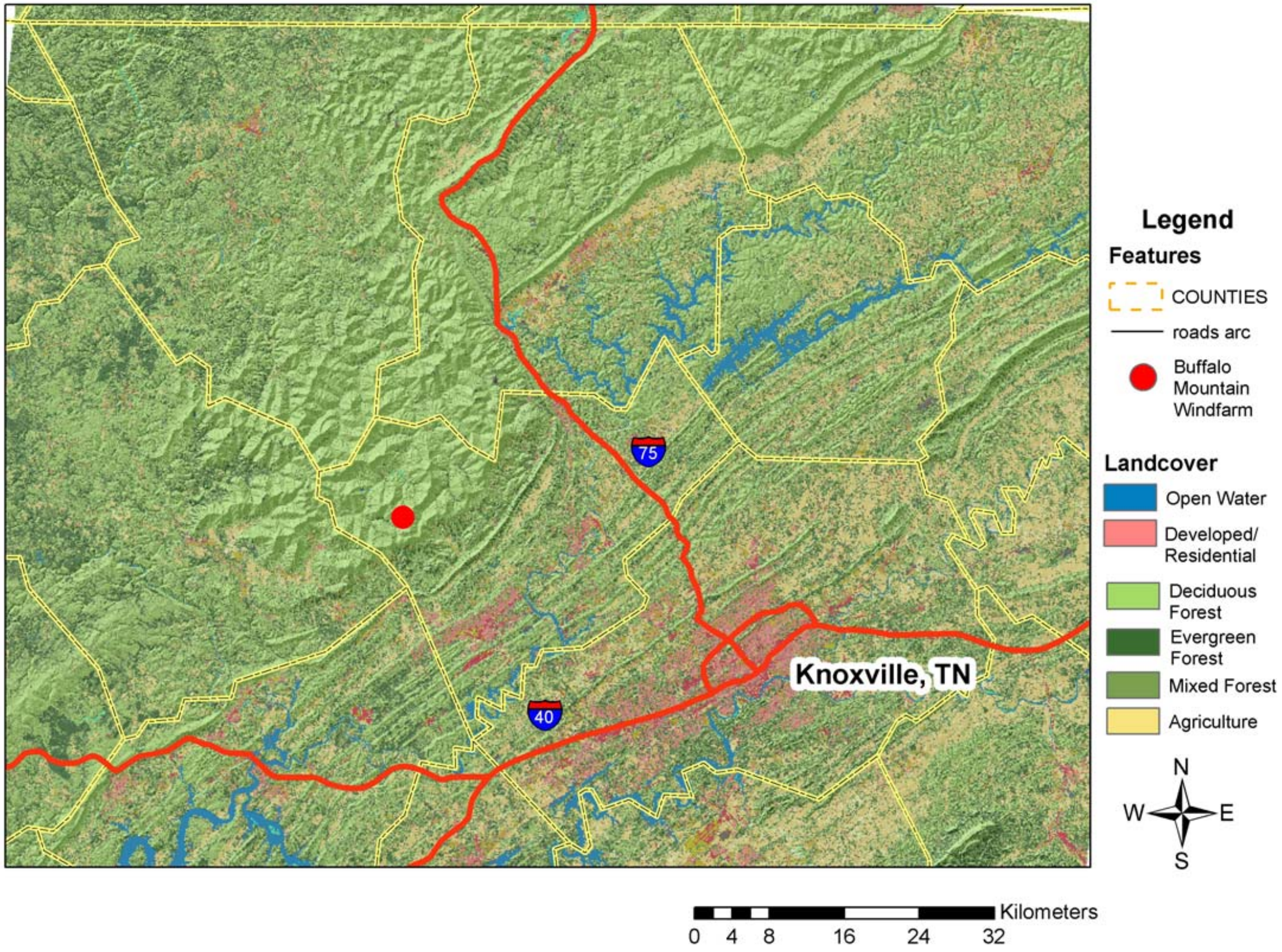


Figure 3. Landcover map showing location of Buffalo Mountain Windfarm in eastern Tennessee.

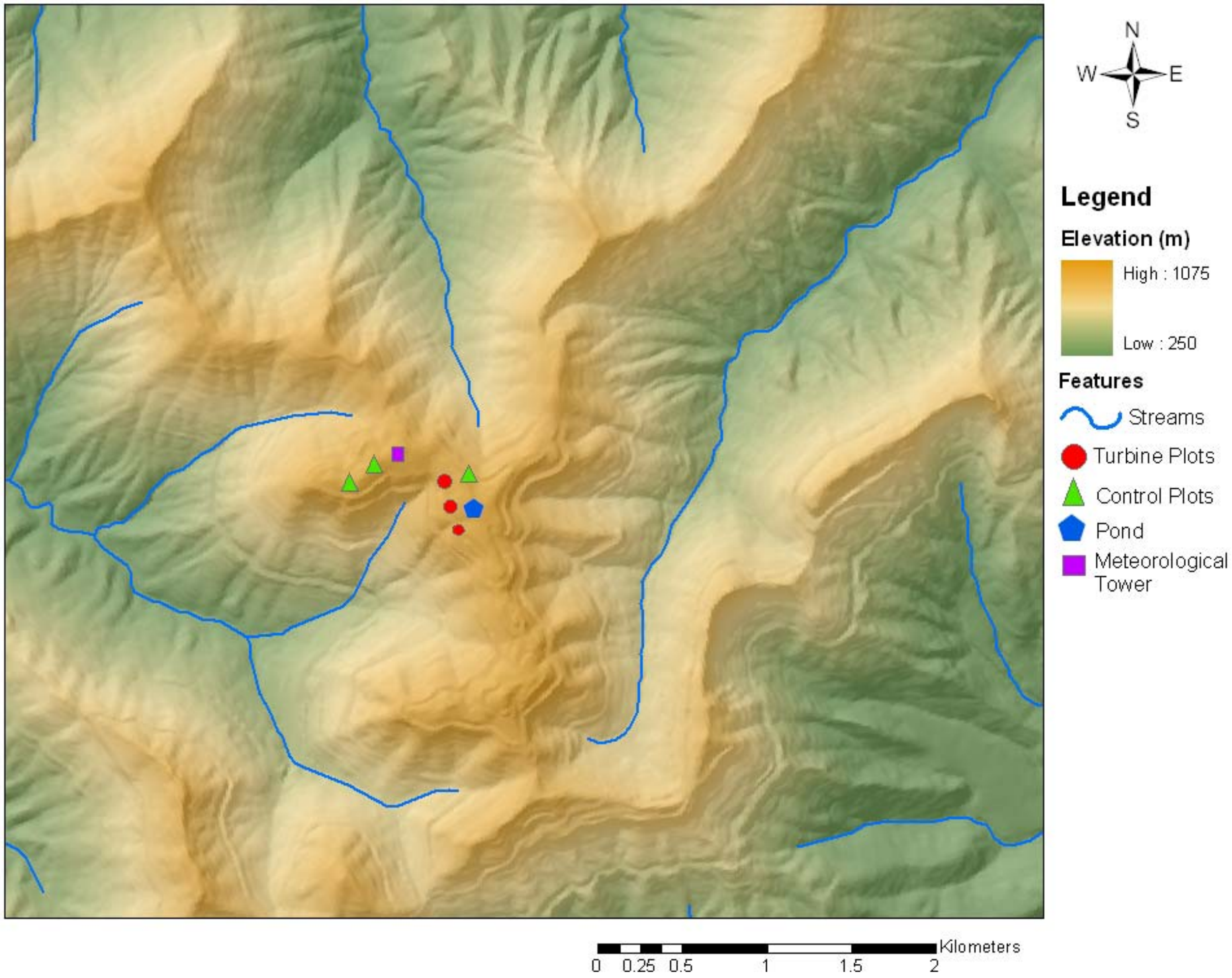


Figure 4. Site map of Buffalo Mountain Windfarm in eastern Tennessee, showing locations of turbines, control plots, meteorological tower, and a nearby pond.

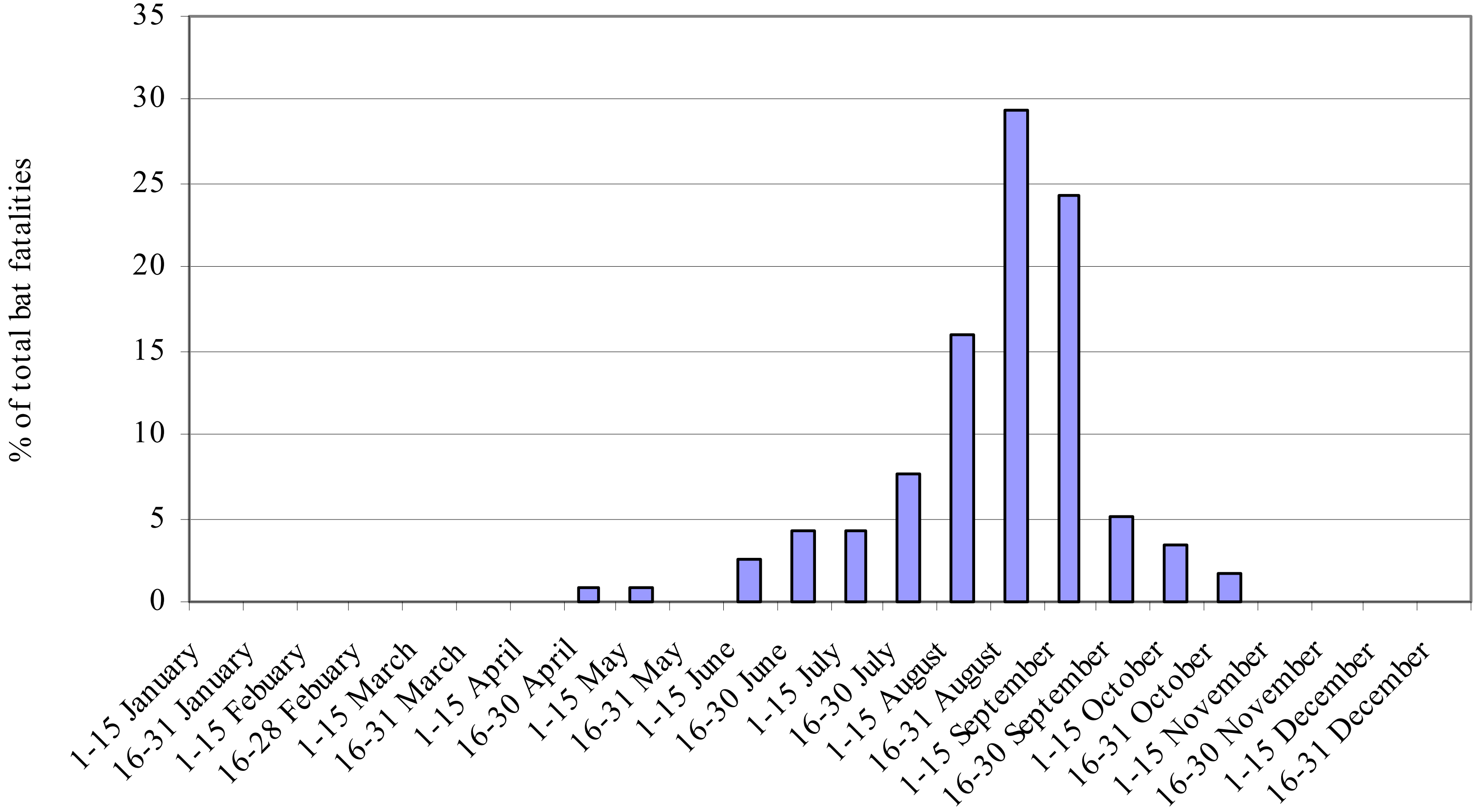


Figure 5. Temporal distribution of bat fatalities (n = 119) at Buffalo Mountain Windfarm, eastern Tennessee, 2000-2003.

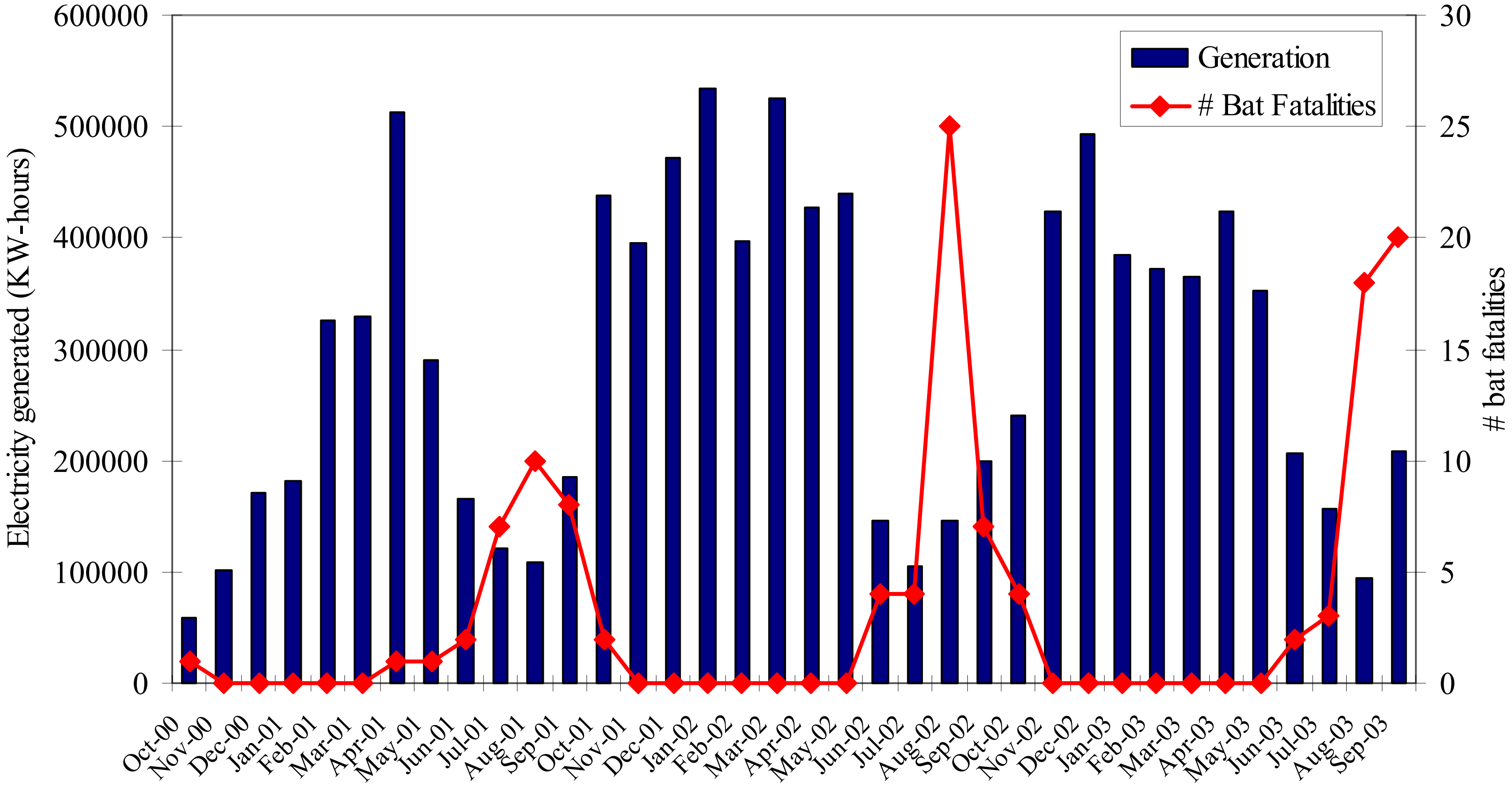


Figure 6. Monthly windfarm generation (kW-hrs) and number of bat fatalities found at Buffalo Mountain Windfarm, eastern Tennessee.

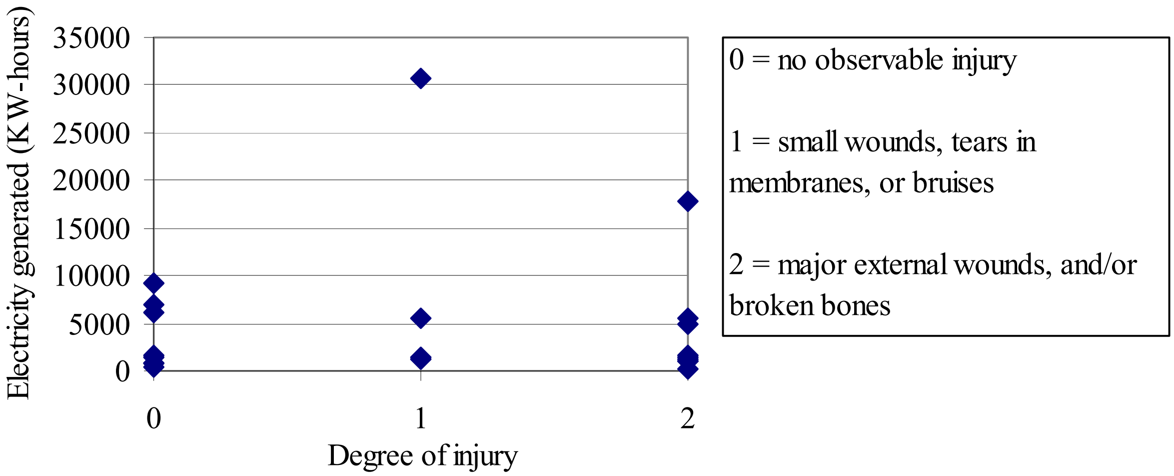


Figure 7. Extent of injuries on bat fatalities and the corresponding daily electrical generation at Buffalo Mountain Windfarm, eastern Tennessee. Only fresh fatalities confidently backdated to a single night between 1 August - 15 September 2002 and 2003 were used (n = 23).

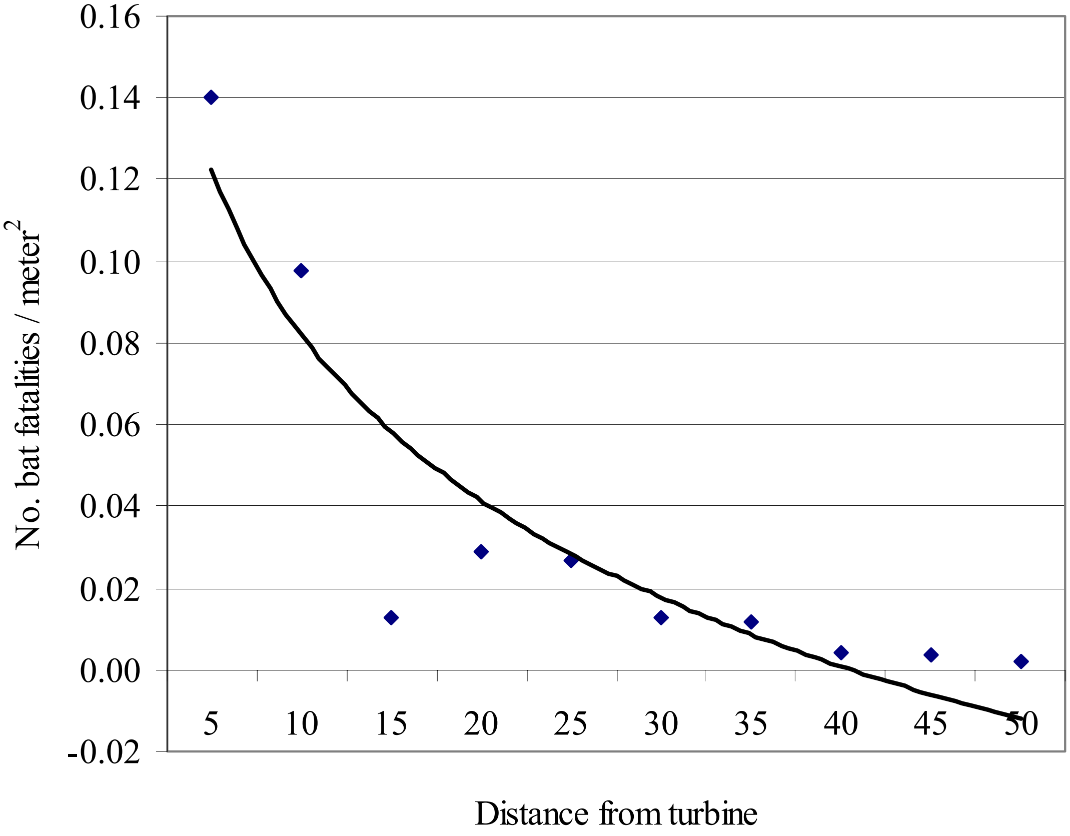
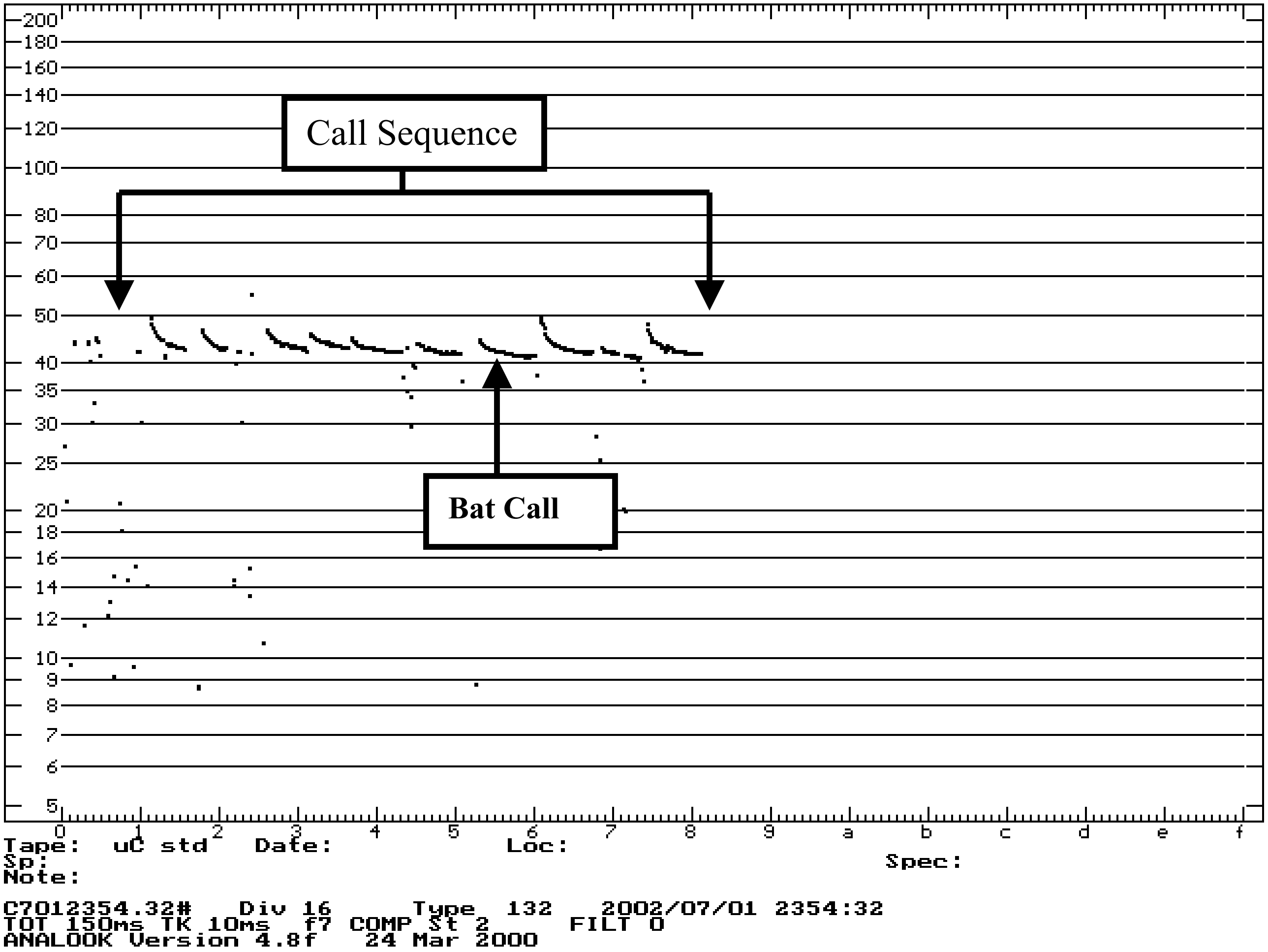


Figure 8. Change in density of bat fatalities with distance from wind turbines at Buffalo Mountain Windfarm, eastern Tennessee ($r^2 = 0.84$, df = 9, $P < 0.01$).



```
Tape:  uC std   Date:                Loc:
Sp:                                                      Spec:
Note:

C7012354.32#    Div 16      Type  132    2002/07/01 2354:32
TOT 150ms TK 10ms  f7 COMP St 2      FILT 0
ANALOOK Version 4.8f   24 Mar 2000
```

Figure 9. Example of bat echolocation call recorded by Anabat II bat detector and displayed by Analook software. For definition purposes, each pulse is referred to as one "bat call" and a string of bat calls is a "call sequence". The digital file encompassing this bat call recording is a "bat file".

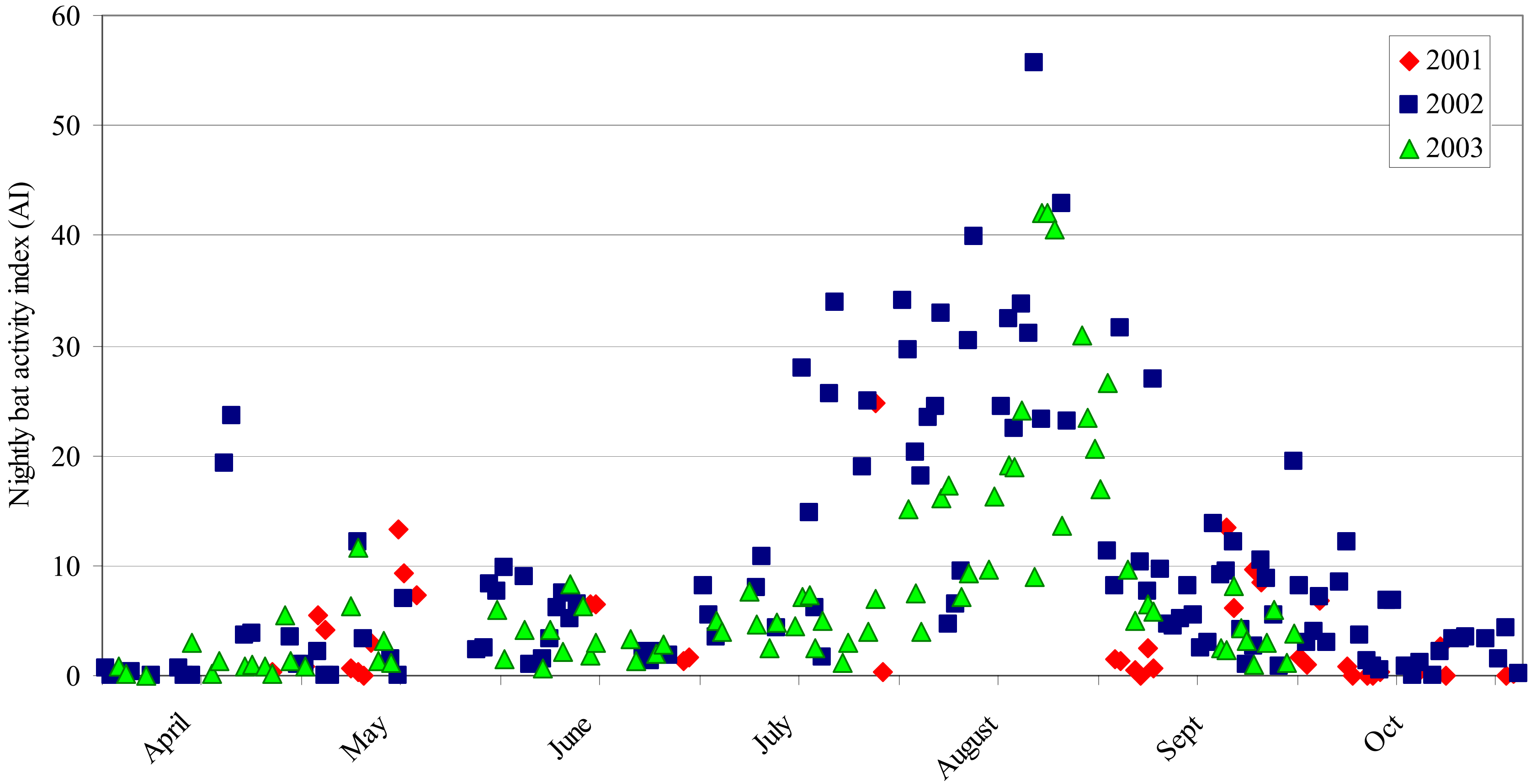


Figure 10. Annual bat activity (AI, measured as the proportion of one-minute increments containing one or more bat call sequences during a night) at the Buffalo Mountain Windfarm, eastern Tennessee, 2001-2003.

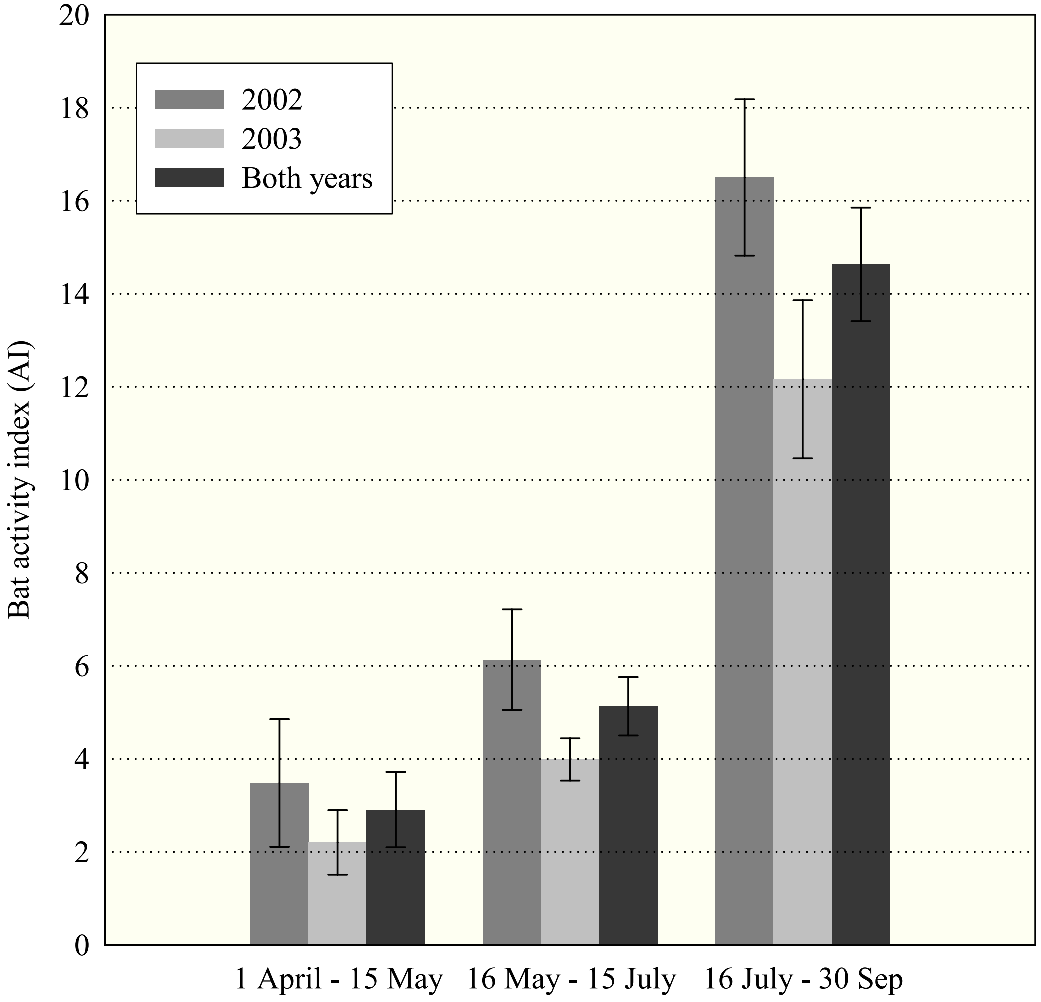


Figure 11. Mean bat activity indices (±SE) (AI, measured as the proportion of one-minute increments containing one or more bat call sequences during a night) by season at Buffalo Mountain Windfarm, eastern Tennessee, for 2002, 2003, and both years (pooled).

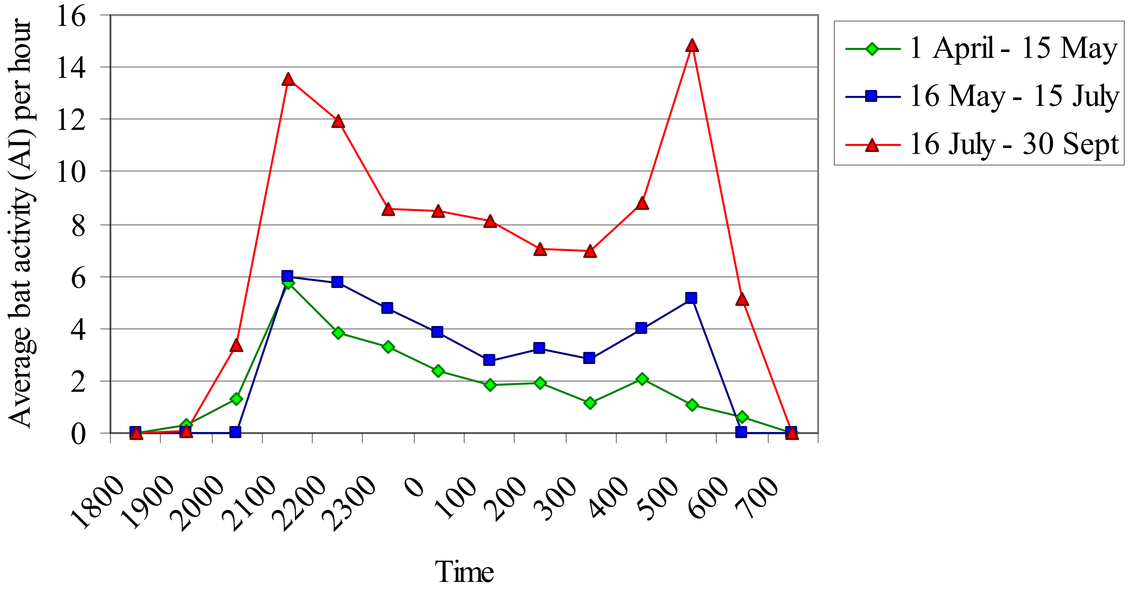


Figure 12. Mean hourly bat activity index (AI, measured as the proportion of one-minute increments containing one or more bat call sequences during a night) by hour for three time periods at Buffalo Mountain Windfarm, eastern Tennessee, 2002.

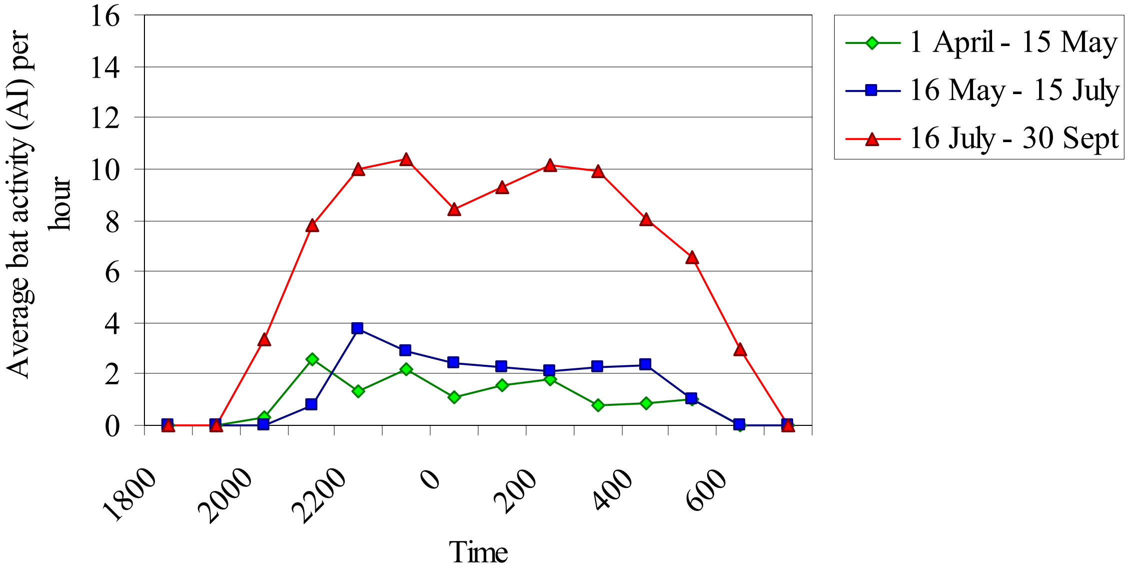


Figure 13. Mean hourly bat activity index (AI, measured as the proportion of one-minute increments containing one or more bat call sequences during a night) by hour for three time periods at Buffalo Mountain Windfarm, eastern Tennessee, 2003.

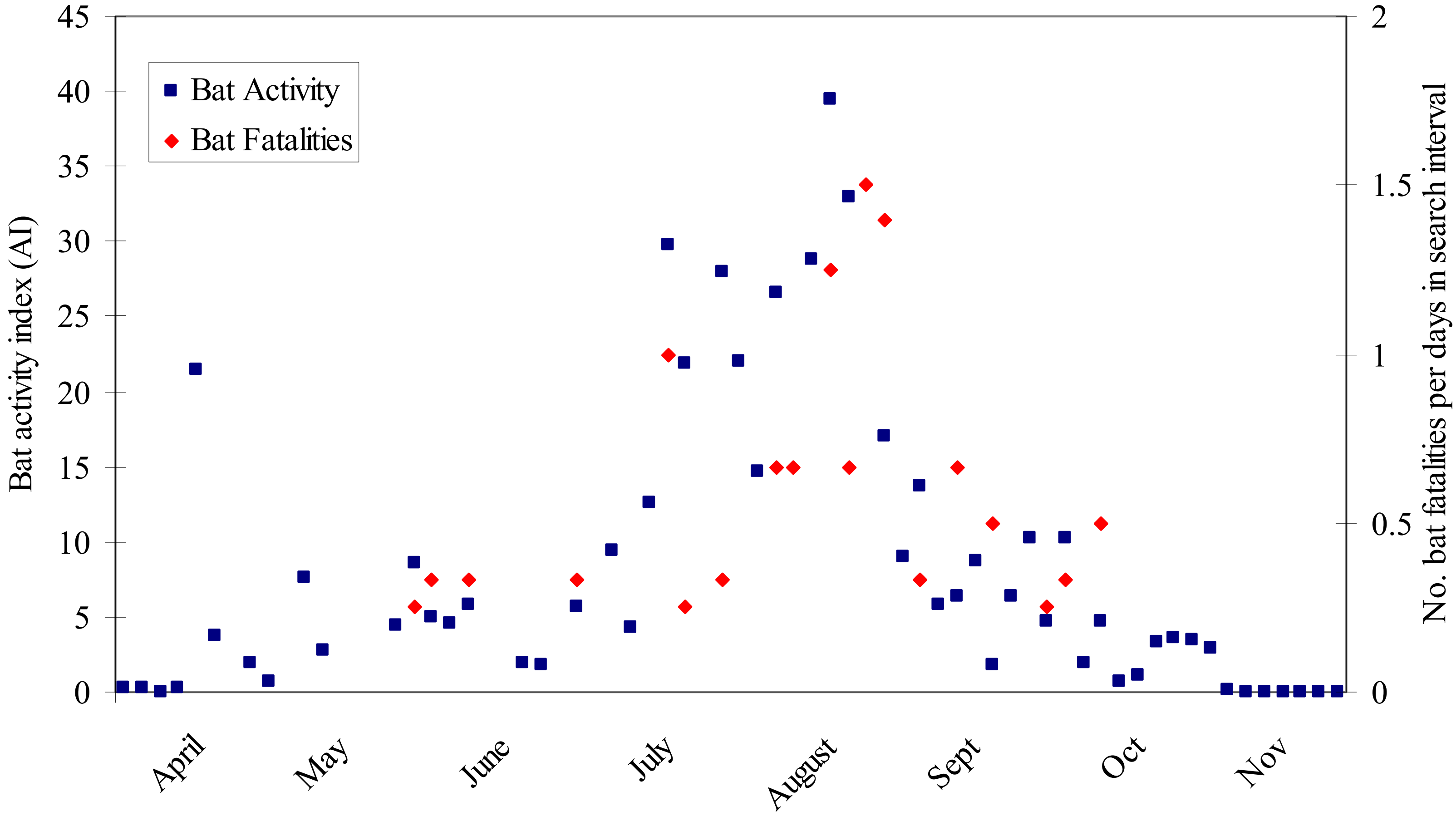


Figure 14. Bat activity index (AI, measured as the proportion of one-minute increments containing one or more bat call sequences during a night) and fatalities at the Buffalo Mountain Windfarm, eastern Tennessee, 2002.

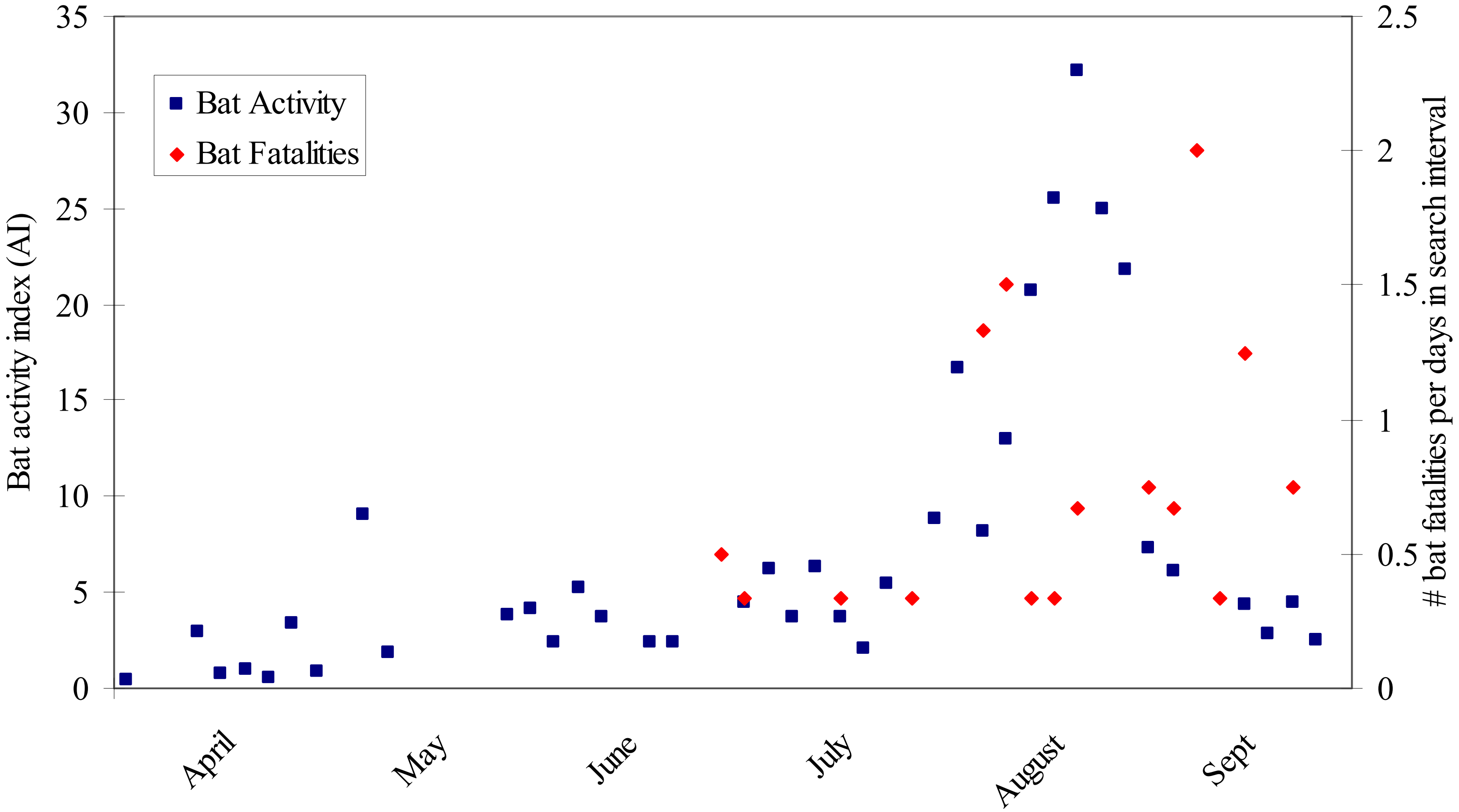


Figure 15. Bat activity index (AI, measured as the proportion of one-minute increments containing one or more bat call sequences during a night) and fatalities at the Buffalo Mountain Windfarm, eastern Tennessee, 2003.

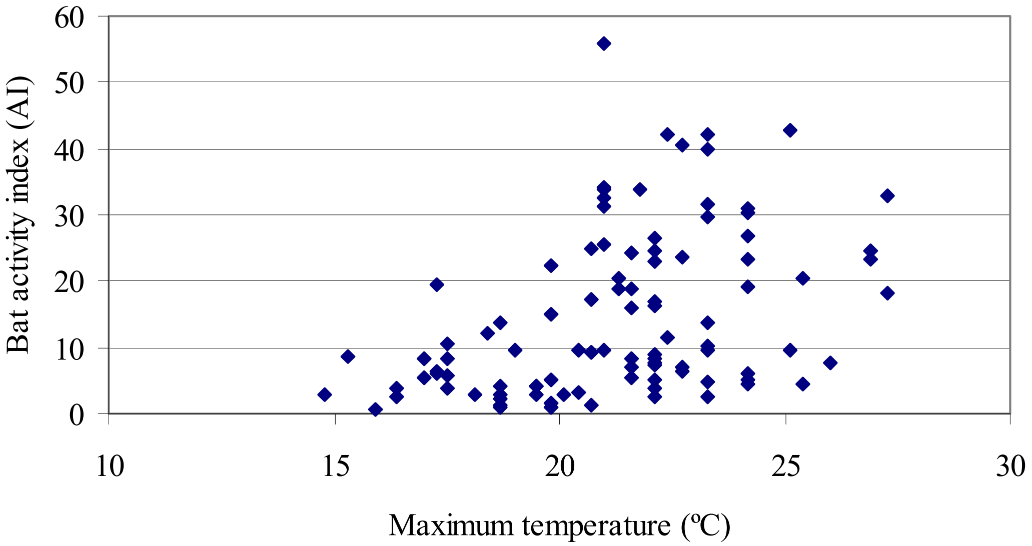


Figure 16. Relationship of nightly maximum temperature with bat activity (proportion of one-minute increments containing more than one bat call sequence during a night) at Buffalo Mountain Windfarm, eastern Tennessee, 16 July - 30 September 2002 & 2003.

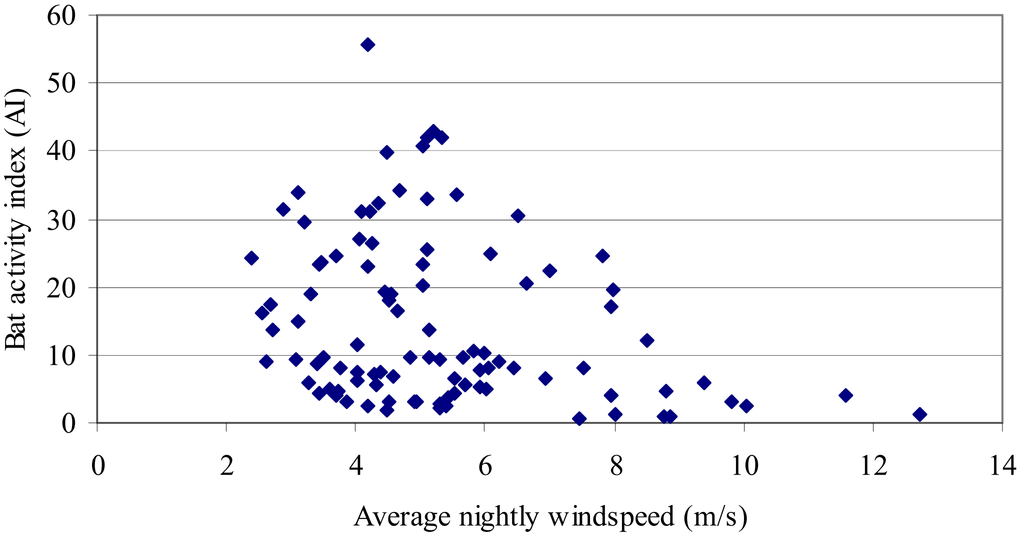


Figure 17. Relationship of average nightly wind speed with bat activity (proportion of one-minute increments containing more than one bat call sequence during a night) at Buffalo Mountain Windfarm, eastern Tennessee, 16 July - 30 September 2002 & 2003.

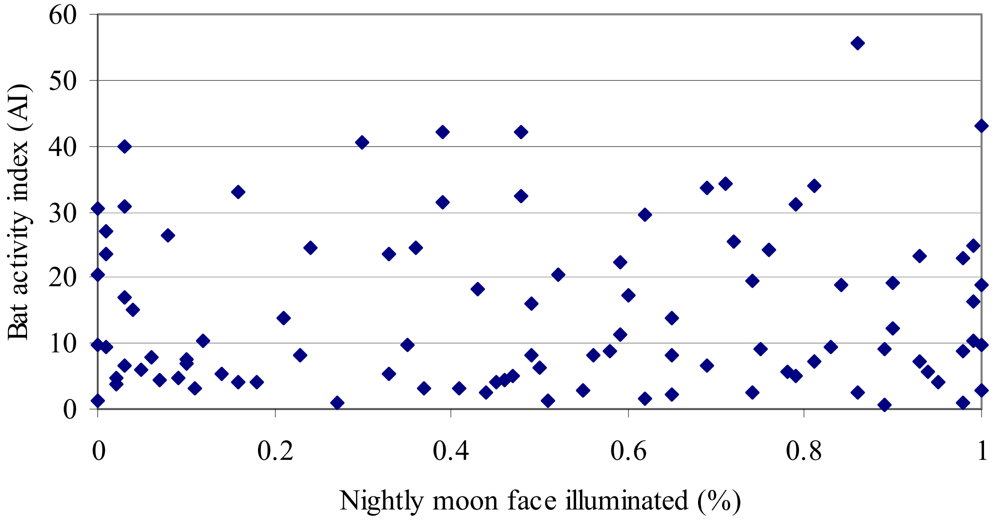


Figure 18. Relationship of nightly moon illumination with bat activity (proportion of one-minute increments containing more than one bat call sequence during a night) at Buffalo Mountain Windfarm, eastern Tennessee, 16 July - 30 September 2002 & 2003.

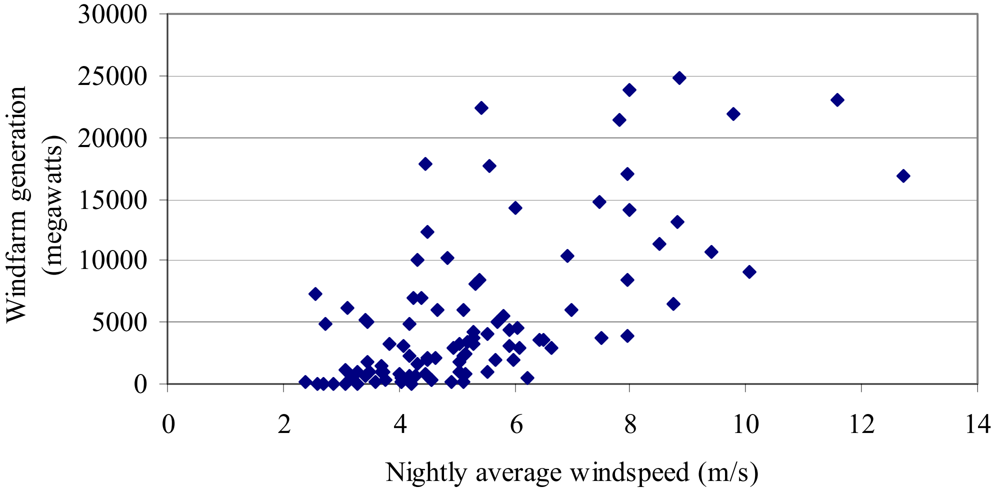


Figure 19. Relationship of nightly wind speed with windfarm generation at Buffalo Mountain Windfarm, eastern Tennessee, 16 July – 30 September 2002 & 2003.

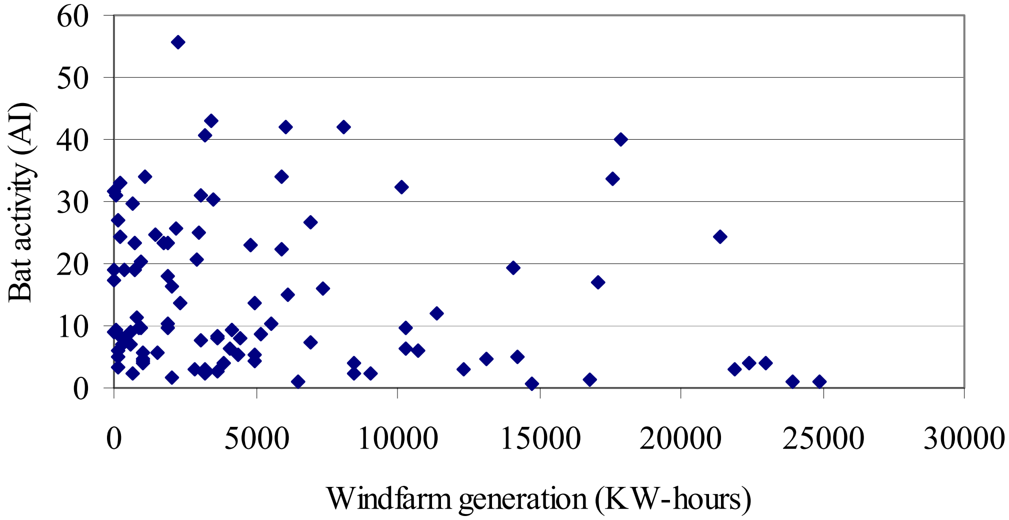


Figure 20. Relationship of nightly windfarm generation with bat activity (proportion of one-minute increments containing more than one bat call sequence during a night) at Buffalo Mountain Windfarm, eastern Tennessee, 16 July - 30 September 2002 & 2003.

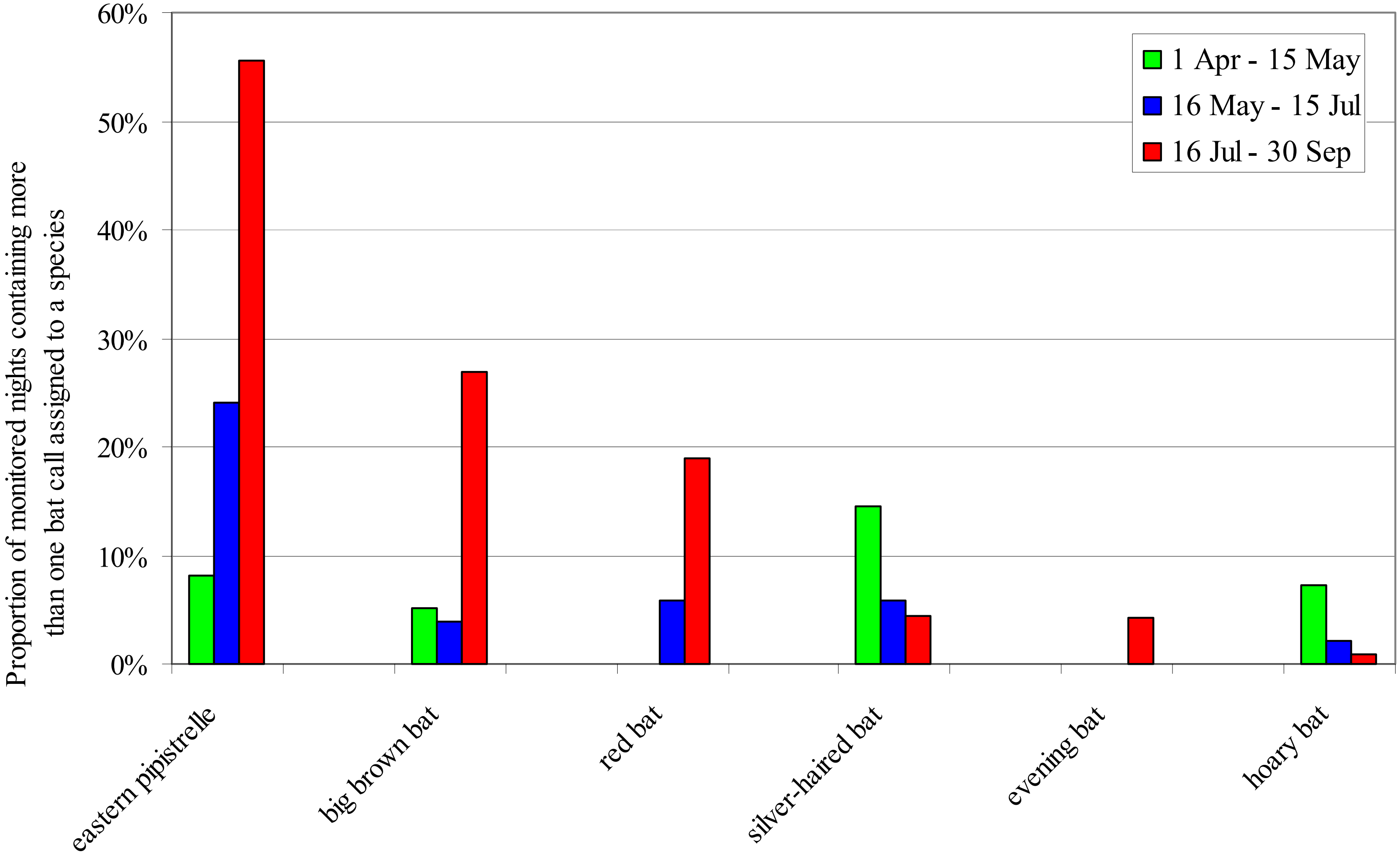
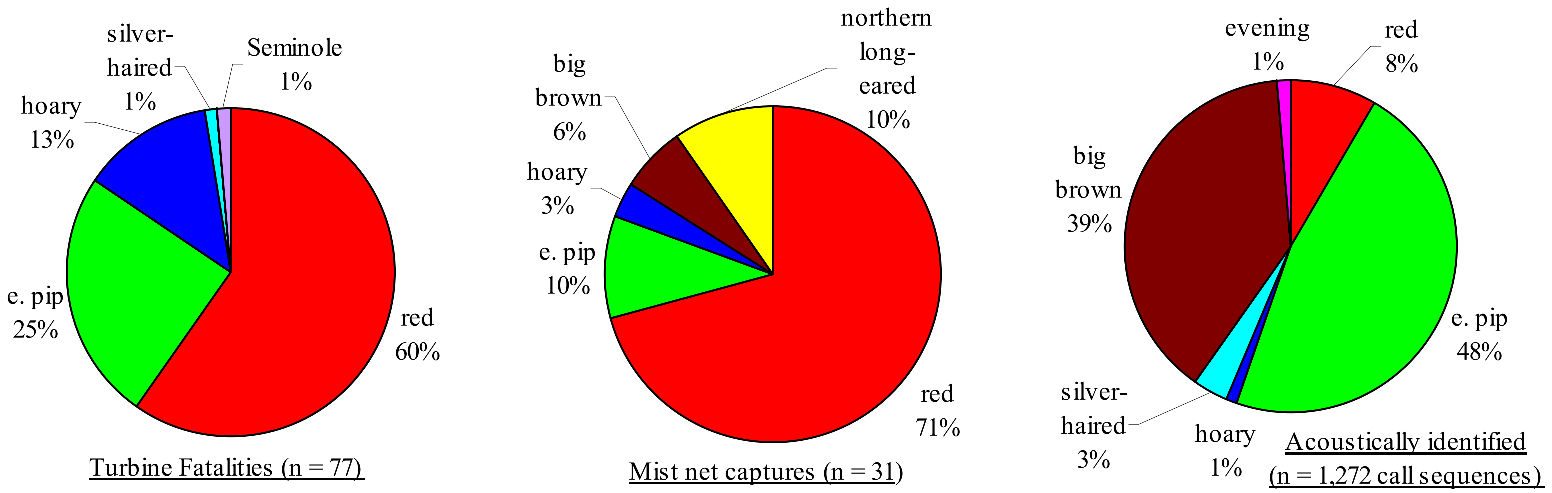


Figure 21. Seasonal distribution of bat species present at Buffalo Mountain Windfarm, eastern Tennessee pond site based on acoustical identification of bat calls.



Turbine Fatalities (n = 77)

Mist net captures (n = 31)

Acoustically identified
(n = 1,272 call sequences)

Figure 22. Comparison of species composition of bat fatalities with bat species detected using acoustical identification and mist-net captures at the Buffalo Mountain Windfarm, eastern Tennessee, during 16 Jul – 30 Sep 2002 and 2003.

APPENDIX B

TABLES

Table 1. Documented bat mortality rates at U.S. windfarms, rates are adjusted for search biases.

Windfarm	Study period	No. turbines	No. bat fatalties / turbine / year	Reference
Buffalo Ridge, MN Phase I	1994-1998	73	0.1	Osborn et al. 1996, Johnson et al. 2000a
Buffalo Ridge, MN Phase II	1998-2001	143	2.0	Erickson et al. 2002
Buffalo Ridge, MN Phase III	1999-2001	138	2.3	Erickson et al. 2002
Foote Creek Rim, WY	1999-2002	105	1.3	Johnson et al. 2000b, Young et al. 2002, 2003b, Gruver 2002
Klondike, OR	2002	16	1.2	Johnson et al. 2003b
Northeastern WI	1999-2001	31	4.3	Howe et al. 2002 as cited by Johnson et al. 2003a
Nine Canyon, WA	2002-2003	37	3.2	Erickson et al. 2003b
Stateline, OR / WA	2001-2002	399	1.0	Erickson et al. 2002
Vanscycle, OR	1999	38	0.7	Erickson et al. 2000
Mountaineer Wind Energy Center, WV	2003	33	47.5	Kerns and Kerlinger 2004

Table 2. Bat species occurring in Tennessee (Barbour and Davis 1969).

Species	Common name	Generalized roosts	Status
Corynorhinus rafinesquii	Rafinesque's big-eared bat	Caves and buildings year-round	Uncommon throughout range, "in need of management" (TWRA)
Eptesicus fuscus	big brown bat	Buildings, hibernate in caves	Common throughout range
Lasionycteris noctivagans	silver-haired bat	Trees and buildings year-round	Uncommon throughout range, Migratory through TN
Lasiurus borealis	eastern red bat	Foliage year-round	Common throughout range
Lasiurus cinereus	hoary bat	Foliage year-round	Common throughout range
*Lasiurus seminolus	Seminole bat	Foliage year-round	Common throughout range
*Myotis austroriparius	southeastern bat	Caves, trees, and buildings year-round	Uncommon throughout range, "species of concern" (USFWS)
Myotis grisescens	gray bat	Caves year-round	Federally endangered
Myotis leibii	eastern small-footed bat	Buildings in summer, caves year-round	Uncommon throughout range, "In need of management" (TWRA)
Myotis lucifugus	little brown bat	Buildings, hibernate in caves	Common in north part of range, locally common in south part of range
Myotis septentrionalis	northern long-eared bat	Caves, trees, and buildings in summer, hibernate in caves	Common throughout range
Myotis sodalis	Indiana bat	Trees, hibernate in caves	Federally endangered
Nycticeius humeralis	evening bat	Trees and buildings, hibernation unknown	Common along southeast coast, less common in TN
Pipistrellus subflavus	eastern pipistrelle	Trees in summer, caves and rock cervices year-round	Common throughout range

* Tennessee range does not historically extend over area containing Bufflao Mountain Windfarm.

Table 3. List of fresh bat fatalities that could be confidently back-dated to an individual night at Buffalo Mountain Windfarm, eastern Tennessee during 2002-2003.

Date	No. bat fatalities
23-Aug-2001	1
2-Sep-2001	3
2-Jun-2002	1
10-Jun-2002	1
21-Jul-2002	1
25-Jul-2002	1
1-Aug-2002	1
10-Aug-2002	1
22-Aug-2002	2
25-Aug-2002	2
29-Aug-2002	2
30-Aug-2002	2
3-Sep-2002	1
15-Sep-2002	1
4-Oct-2002	1
28-Jun-2003	1
16-Jul-2003	1
14-Aug-2003	1
17-Aug-2003	1
20-Aug-2003	1
4-Sep-2003	2
8-Sep-2003	3
11-Sep-2003	1
15-Sep-2003	2
22-Sep-2003	1

Table 4. Dates carcass searches were conducted at Buffalo Mountain Windfarm, eastern Tennessee during the duration of this study, September 2000 – September 2003.

2000
September 26, 28
October 2, 5, 10, 13, 17, 20, 24, 27
November 1, 8, 21
December 7, 27

2001
January 23
February 6, 20
March 6, 15, 22, 27
April 3, 5, 10, 12, 17, 19, 24, 26
May 1, 3, 8, 10, 15, 18, 23, 29
June 1, 7, 15, 22, 27
July 6, 13, 20, 25
August 3, 8, 17, 24, 27, 31
September 3, 8, 10, 14, 17, 21, 24, 28
October 1, 5, 8, 12, 15, 19, 22, 26, 29
November 2, 5, 14, 21, 28
December 5, 19

2002
January 4, 18
February 4, 18, 25
March 4, 11, 19, 25
April 1, 5, 8, 12, 19, 22, 26, 29
May 3, 6, 9, 14, 17, 20, 22, 27,30
June 3, 6, 10, 13, 18, 21, 25, 27, 30
July 3, 8, 11, 15, 19, 22, 26, 30
August 2, 5, 8, 11, 14, 19, 23, 26, 30
September 4, 6, 9, 11, 13, 16, 20, 22, 27, 30
October 4, 7, 10, 14, 21, 24, 28, 31
November 3, 13, 18, 25, 30
December 2, 16, 30

Table 4. continued

2003
January 14, 28
February 12
March 4, 11, 20, 24, 31
April 3, 7, 10, 14, 17, 22, 25, 28
May 1, 5, 8, 12, 15, 19, 23, 27, 30
June 3, 6, 9, 12, 16, 19, 23, 27, 29
July 2, 7, 10, 14, 17, 21, 25, 28, 31
August 5, 8, 12, 15, 18, 21, 26, 29
September 2, 5, 9, 12, 16, 19, 23 ,26, 30

Table 5. Bat fatalities found at Buffalo Mountain Windfarm, eastern Tennessee, during carcass searches from 26 September 2000 through 30 September 2003.

Date Found	Turbine	Species	Age	Sex	Distance (m) from turbine	Bearing from turbine	Degree of injury
2000							
1 Nov	3	Lasiurus borealis	Adult	Male	27.2	174	0
2001							
3 May	2	Lasiurus borealis	Adult	Male	35.4	16	0
3 May	2	Pipistrelle subflavus	Adult	Male	25.4	14	0
6 Jul	2	Lasiurus borealis	Adult	Unknown	50.0	348	0
6 Jul	2	Pipistrelle subflavus	Adult	Female	12.0	334	2
6 Jul	2	Pipistrelle subflavus	Juvenile	Male	2.0	324	na
13 Jul	2	Lasiurus borealis	Adult	Unknown	6.0	332	na
13 Jul	2	Lasiurus borealis	Juvenile	Male	7.2	306	0
13 Jul	2	Lasiurus borealis	Adult	Male	2.3	224	na
13 Jul	3	Lasiurus borealis	Adult	Unknown	7.0	10	na
25 Jul	3	Pipistrelle subflavus	Adult	Female	13.1	82	0
25 Jul	1	Lasiurus borealis	Adult	Male	6.7	342	1
8 Aug	1	Lasiurus borealis	Juvenile	Male	28.0	340	na
8 Aug	2	Pipistrelle subflavus	Adult	Female	22.0	41	na
24 Aug	3	Lasiurus borealis	Adult	Female	33.0	42	2
27 Aug	3	Lasiurus borealis	Adult	Unknown	17.1	57	2
27 Aug	3	Pipistrelle subflavus	Adult	Male	17.1	90	0
27 Aug	3	Pipistrelle subflavus	Adult	Male	17.1	202	2
27 Aug	2	Eptesicus fuscus	Adult	Male	6.8	277	2
27 Aug	2	Pipistrelle subflavus	Adult	Male	16.2	302	0
27 Aug	1	Lasiurus borealis	Adult	Female	15.1	300	2
27 Aug	1	Lasiurus borealis	Adult	Unknown	6.4	235	2
3 Sep	3	Lasiurus borealis	Adult	Female	2.4	230	2
3 Sep	2	Lasiurus borealis	Adult	Female	12.3	25	0
3 Sep	2	Lasiurus cinereus	Adult	Female	6.5	162	0
5 Sep	2	Lasiurus borealis	Adult	Female	8.3	324	0
9 Sep	1	Lasiurus borealis	Unknown	Unknown	8.9	344	na
12 Sep	1	Pipistrelle subflavus	Unknown	Unknown	4.9	288	na
14 Sep	2	Lasiurus borealis	Adult	Unknown	6.4	10	na
1 Oct	3	Lasionycteris noctivagans	Juvenile	Male	31.8	353	0
5 Oct	1	Lasiurus borealis	Adult	Male	6.3	20	2
2 Nov	2	Lasiurus borealis	Adult	Male	22.6	328	1
2002							
3 Jun	1	Lasiurus borealis	Juvenile	Male	17.2	135	2
6 Jun	3	Lasiurus borealis	Juvenile	Unknown	20.5	92	na

**Four bat fatalities found during non-search related activites.*

Table 5 continued.

Date Found	Turbine	Species	Age	Sex	Distance (m) from turbine	Bearing from turbine	Degree of injury
*11 Jun**	*2*	*Eptesicus Fuscus*	*Juvenile*	*Male*	*73.3*	*70*	*2*
3 Jul	2	Lasiurus borealis	Juvenile	Unknown	23.9	286	na
22 Jul	3	Pipistrelle subflavus	Adult	Unknown	16.7	122	2
22 Jul	2	Lasiurus cinereus	Adult	Female	10.0	316	2
22 Jul	2	Lasiurus cinereus	Juvenile	Male	5.1	264	1
26 Jul	2	Lasiurus borealis	Juvenile	Male	4.9	265	2
2 Aug	1	Pipistrelle subflavus	Juvenile	Male	2.7	240	2
11 Aug	1	Lasiurus cinereus	Adult	Unknown	28.9	271	2
11 Aug	2	Lasiurus borealis	Adult	Unknown	24.1	73	na
14 Aug	3	Lasiurus borealis	Juvenile	Male	9.1	240	1
14 Aug	3	Lasiurus cinereus	Adult	Unknown	44.1	321	2
23 Aug	3	Lasiurus borealis	Juvenile	Unknown	5.8	132	na
23 Aug	3	Lasiurus borealis	Unknown	Female	20.5	43	1
23 Aug	3	Lasiurus borealis	Unknown	Male	33.5	65	2
23 Aug	3	Lasiurus borealis	Unknown	Unknown	56.8	94	na
23 Aug	3	Lasiurus borealis	Unknown	Female	9.4	306	2
26 Aug	2	Lasiurus borealis	Adult	Unknown	8.3	84	na
26 Aug	1	Lasiurus borealis	Adult	Female	5.1	256	1
26 Aug	1	Lasiurus borealis	Adult	Male	30.1	154	2
30 Aug	2	Lasiurus borealis	Adult	Male	20.2	340	2
30 Aug	2	Lasiurus cinereus	Unknown	Male	16.5	325	2
30 Aug	2	Lasiurus borealis	Adult	Female	32.6	22	2
30 Aug	2	Lasiurus borealis	Adult	Male	30.1	2	2
30 Aug	1	Lasiurus borealis	Unknown	Female	5.6	348	2
30 Aug	1	Pipistrelle subflavus	Adult	Unknown	23.6	280	na
30 Aug	3	Lasiurus cinereus	Unknown	Male	47.7	65	2
*31 Aug**	*2*	*Lasiurus borealis*	*Adult*	*Male*	*18.9*	*344*	*0*
*31 Aug**	*2*	*Lasiurus cinereus*	*Unknown*	*Female*	*20.2*	*266*	*0*
4 Sep	3	Lasiurus borealis	Adult	Male	5.0	60	1
4 Sep	1	Lasiurus borealis	Unknown	Male	35.4	158	1
4 Sep	1	Lasiurus borealis	Unknown	Unknown	47.0	222	na
4 Sep	1	Lasiurus cinereus	Adult	Male	22.9	24	2
4 Sep	2	Lasiurus borealis	Adult	Male	32.6	350	na
4 Sep	2	Lasiurus borealis	Unknown	Unknown	6.0	338	2
9 Sep	2	Lasiurus cinereus	Unknown	Male	4.7	72	2
16 Sep	1	Lasiurus borealis	Unknown	Male	30.1	130	2
16 Sep	3	Lasiurus borealis	Juvenile	Male	29.4	115	2
22 Sep	2	Lasiurus borealis	Unknown	Male	40.0	54	2
4 Oct	2	Lasiurus borealis	Adult	Male	28.6	84	2

**Four bat fatalities found during non-search related activites.*

Table 5 continued.

Date Found	**Turbine**	**Species**	**Age**	**Sex**	**Distance (m) from turbine**	**Bearing from turbine**	**Degree of injury**
*5 Oct**	*3*	*Lasiurus borealis*	*Juvenile*	*Male*	*~30m*	*~100*	*1*
14 Oct	3	Lasiurus borealis	Adult	Male	37.4	98	2
14 Oct	2	Lasiurus borealis	Adult	Male	20.3	60	2
2003							
29 Jun	1	Pipistrelle subflavus	Adult	Male	24.4	115	1
2 Jul	1	Lasiurus cinereus	Adult	Unknown	32.4	208	2
17 Jul	1	Lasiurus borealis	Adult	Male	11.2	218	0
28 Jul	1	Lasiurus borealis	Adult	Male	4.2	30	1
8 Aug	3	Lasiurus borealis	Adult	Unknown	40.0	80	na
8 Aug	2	Lasiurus borealis	Juvenile	Male	6.8	182	2
8 Aug	2	Pipistrelle subflavus	Juvenile	Female	27.8	238	1
8 Aug	1	Pipistrelle subflavus	Adult	Female	7.5	210	1
8 Aug	1	Pipistrelle subflavus	Juvenile	Male	2.4	331	0
12 Aug	3	Lasiurus borealis	Juvenile	Unknown	13.4	197	1
12 Aug	3	Pipistrelle subflavus	Juvenile	Male	18.4	261	1
12 Aug	3	Lasiurus borealis	Juvenile	Female	25.5	334	2
12 Aug	1	Pipistrelle subflavus	Juvenile	Female	4.1	276	2
12 Aug	1	Pipistrelle subflavus	Juvenile	Male	21.2	291	1
12 Aug	1	Lasiurus borealis	Juvenile	Unknown	23.7	258	2
15 Aug	1	Pipistrelle subflavus	Juvenile	Male	19.0	6	0
18 Aug	3	Lasiurus borealis	Juvenile	Unknown	22.2	223	2
21 Aug	3	Lasiurus borealis	Juvenile	Unknown	2.6	251	2
21 Aug	2	Lasiurus borealis	Juvenile	Male	34.1	346	0
21 Aug	1	Pipistrelle subflavus	Unknown	Unknown	31.2	140	2
2 Sep	1	Lasiurus borealis	Adult	Male	21.4	69	2
2 Sep	2	Pipistrelle subflavus	Unknown	Male	18.0	87	2
2 Sep	2	Lasiurus borealis	Juvenile	Unknown	43.1	20	1
5 Sep	3	Lasiurus borealis	Juvenile	Female	27.9	181	0
5 Sep	1	Lasiurus borealis	Juvenile	Male	22.1	188	0
9 Sep	3	Pipistrelle subflavus	Adult	Male	8.8	30	0
9 Sep	1	Pipistrelle subflavus	Adult	Male	25.9	342	0
9 Sep	1	Lasiurus borealis	Adult	Male	24.3	22	2
9 Sep	1	Lasiurus borealis	Adult	Male	24.0	270	0
9 Sep	1	Lasionycteris noctivagans	Adult	Male	36.7	12	1
9 Sep	1	Pipistrelle subflavus	Juvenile	Male	28.5	5	2
9 Sep	1	Lasiurus borealis	Juvenile	Female	16.5	88	0
9 Sep	1	Pipistrelle subflavus	Juvenile	Male	22.9	342	1
12 Sep	3	Pipistrelle subflavus	Unknown	Unknown	19.5	210	na
12 Sep	3	Pipistrelle subflavus	Juvenile	Male	31.8	258	0

**Four bat fatalities found during non-search related activites.*

Table 5 continued.

Date Found	**Turbine**	**Species**	**Age**	**Sex**	**Distance (m) from turbine**	**Bearing from turbine**	**Degree of injury**
16 Sep	3	Lasiurus borealis	Adult?	Female	16.1	123	0
16 Sep	3	Lasiurus seminolus	Adult	Male	18.5	126	0
16 Sep	3	Pipistrelle subflavus	Adult	Male	17.3	170	1
16 Sep	3	Lasiurus borealis	Juvenile	Female	37.8	51	0
16 Sep	1	Lasiurus borealis	Adult	Female	34.5	120	2
23 Sep	2	Lasiurus cinereus	Adult	Male	3.2	132	2
23 Sep	3	Lasiurus borealis	Adult	Male	5.3	19	2
23 Sep	3	Lasiurus borealis	Juvenile	Male	40.4	184	1

**Four bat fatalities found during non-search related activites.*

Table 6. List of bat fatalities found at Buffalo Mountain Windfarm, eastern Tennessee and circumstances excluding them from some analyses.

Date found	Species	Plot	> 50 m[a]	Still alive[b]	Not found on carcass searches[a]
15 Jun 2001	red bat[c]	C1			x
3 Sep 2001	red bat	T3		x	
11 Jun 2002	big brown bat	T2	x	x	x
22 Jul 2002	hoary bat	T2		x	
23 Aug 2002	red bat	T3	x		
31 Aug 2002	red bat	T2			x
31 Aug 2002	hoary bat	T2			x
5 Oct 2002	red bat	T3			x
8 Aug 2003	eastern pipistrelle	T1		x	
16 Sep 2003	red bat	T1		x	

[a] Excluded from spatial analyses and mortality estimates.

[b] Excluded from spatial analyses only.

[c] Probable mist-net fatality from previous night, excluded from all analyses.

Table 7. Distribution of bat fatalities by species and turbine at Buffalo Mountain Windfarm, eastern Tennessee, 2000 - 2003.

Species	Turbine 1	Turbine 2	Turbine 3	All Turbines
red bat	21	24	23	68
eastern pipistrelle	12	7	9	28
hoary bat	3	5	2	10
big brown bat	0	1	0	1
silver-haired bat	1	0	1	2
Seminole bat	0	0	1	1
All Species	**37**	**37**	**36**	**110**

Table 8. Seasonal distribution of bat fatalities found at Buffalo Mountain Windfarm, eastern Tennessee, 2000-2003. Numbers and percents are for fatalities observed annually during each seasonal time period.

	2000[a]		2001		2002		2003[b]		All years	
	No.	Annual %	No.	Annual %	No.	Annual %	No.	Annual %	No.	Annual %
1 April - 15 May	-	-	2	6.5	0	0.0	0	0.0	2	1.7
16 May - 15 July	-	-	7	22.6	4	9.1	2	4.7	13	10.9
15 July - 30 Sep	0	0.0	21	71.0	36	81.8	41	95.3	98	82.4
1 Oct - 31 March	1	100.0	1	0.0	4	0.1	-	-	6	5.0
Total	1		31		44		43		119	

[a] Carcass searches began 26 September 2000, shortly after BMW became operational.

[b] The three-year monitoring period for this project ended 30 September 2003.

Table 9. Timing of bat fatalities at Buffalo Mountain Windfarm, eastern Tennessee, 2000-2003. Dates of death for fatalities found near a cutoff date were estimated based on recorded condition. Numbers and percents are for fatalities observed for each year and all years combined.

	2000[a]		2001		2002		2003[b]		All years	
	No.	%	No.	%	No.	%	No.	%	No.	%
1-15 January			0		0		0		0	
16-31 January			0		0		0		0	
1-15 Febuary			0		0		0		0	
16-28 Febuary			0		0		0		0	
1-15 March			0		0		0		0	
16-31 March			0		0		0		0	
1-15 April			0		0		0		0	
16-30 April			1	3.2	0		0		1	0.8
1-15 May			1	3.2	0		0		1	0.8
16-31 May			0		0		0		0	
1-15 June			0		3	6.8	0		3	2.5
16-30 June			2	6.5	1	2.3	2	4.7	5	4.2
1-15 July			5	16.1	0		0		5	4.2
16-30 July			2	6.5	4	9.1	3	7.0	9	7.6
1-15 August			2	6.5	5	11.4	12	27.9	19	16.0
16-31 August			10	32.3	19	43.2	6	14.0	35	29.4
1-15 September			5	16.1	7	15.9	17	39.5	29	24.4
16-30 September	0		2	6.5	1	2.3	3	7.0	6	5.0
1-15 October	0		0		4	9.1			4	3.4
16-31 October	1	100.0	1	3.2	0				2	1.7
1-15 November	0		0		0				0	
16-30 November	0		0		0				0	
1-15 December	0		0		0				0	
16-31 December	0		0		0				0	
Total	1		31		44		43		119	

[a] Carcass searches began 26 September, shortly after BMW became operational.

[b] The three-year monitoring period for this project ended 30 September 2003.

Table 10. Species composition of bat fatalities found at Buffalo Mountain Windfarm, eastern Tennessee, 2000-2003. Numbers and percents are for the observed fatalities during each year and all years combined.

	2000		2001		2002		2003		All years	
	No.	%	No.	%	No.	%	No.	%	No.	%
red bat	1	100.0	19	61.3	31	70.5	22	51.2	73	61.3
eastern pipistrelle	0	0	9	29.0	3	6.8	17	39.5	29	24.4
hoary bat	0	0	1	3.2	9	20.5	2	4.7	12	10.1
silver-haired bat	0	0	1	3.2	0	0	1	2.3	2	1.7
big brown bat	0	0	1	3.2	1	2.3	0	0	2	1.7
Seminole bat	0	0	0	0	0	0	1	2.3	1	0.8
Total	1	100.0	31	100.0	44	100.0	43	100.0	119	100.0

Table 11. Age and sex by species of bat fatalities found at Buffalo Mountain Windfarm, eastern Tennessee, 2000-2003.

	red bat		eastern pipistrelle		hoary bat		silver-haired bat		big brown bat		Seminole bat		all bats	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Male	36	49.3	17	58.6	6	50.0	2	100.0	2	100.0	1	100.0	64	53.8
Female	16	21.9	6	20.7	3	25.0	0	0	0	0	0	0	25	21.0
Unknown	21	28.8	6	20.7	3	25.0	0	0	0	0	0	0	30	25.2
Adult	37	50.7	14	48.3	7	58.3	1	50.0	1	50.0	1	100.0	61	51.3
Juvenile	22	30.1	10	34.5	1	8.3	1	50.0	1	50.0	0	0	35	29.4
Unknown	13	17.8	5	17.2	4	33.3	0	0	0	0	0	0	22	18.5
Total	73	61.3	29	24.4	12	10.1	2	1.7	2	1.7	1	0.8	119	

Table 12. Variables used to model whether a fatality occurred on a night and the corresponding logistic regression Akaike Information Criteria (AIC) regression coefficients used to select models. All models within 2 AIC values of the lowest scoring model were kept.

AIC Score	No. Variables	Average nightly windspeed	Windspeed difference[a]	Average nightly wind direction	Wind direction difference[a]	Maximum nightly temperature	Nightly temperature range
57.459	3	-0.41	-0.81	1.17*			
57.633	4	-0.39	-0.81	1.00*		-0.18	
57.641	3		-1.03*	0.88		-0.19	
57.893	2		-1.01*	1.03*			
58.362	2	-0.55*		1.07*			
58.373	5	-0.62	-0.85	1.06*		-0.26	-0.34
58.565	3	-0.56*		0.93*		-0.11	
58.954	5	-0.46	-0.83	0.97*	-0.01	-0.20	
59.361	4	-0.77*		0.90		-0.25	-0.31
No. times variable used		7	6	9	1	6	2

[a] Differences were calculated as the difference between the average values of early night (1800 - 2400 hours) and late night (2400 - 0600 hours).

*Denotes signficant variables in the model.

Table 13. Searcher efficiency and carcass removal estimates for six search bias trials at Buffalo Mountain Windfarm, eastern Tennessee, 2000 – 2003.

Carcass Detectability and Removal Study	Date started	Grouping	No. carcasses placed	No. carcasses not scavenged and available to be found	No. carcasses found	Searcher efficiency (e)	Average no. of days carcass remained (t)
I	9 Sep 2001	bird	10	7	1	14.3%	16.71
		bat	-			-	-
		overall	10	7	1	14.3%	16.71
II	18 Feb 2002	bird	25	12	5	41.7%	3.21
		bat	-			-	-
		overall	25	12	5	41.7%	3.21
III	5 Aug 2002	bird	21	10	7	70.0%	4.79
		bat	10	6	5	83.3%	4.94
		overall	31	16	12	75.0%	4.84
IV	20 Sep 2002	bird	-			-	-
		bat	22	11	1	9.1%	4.67
		overall	22	11	1	9.1%	4.67
V	12 May 2003	bird	15	13	5	38.5%	5.57
		bat	14	12	3	25.0%	6.19
		overall	29	25	8	32.0%	5.87
VI	21 Jul 2003	bird	18	13	5	38.5%	7.28
		bat	16	13	8	61.5%	13.85
		overall	34	26	13	50.0%	10.20
Total		**bird**	**89**	**55**	**23**	**40.6%***	**5.81***
		bat	**62**	**42**	**17**	**44.7%***	**7.03***
		overall	**151**	**97**	**40**	**37.0%***	**6.31***

* Averages of trials for each group: bird (n = 5), bat (n = 4), overall (n = 6)

Table 14. List of possible scavengers observed at Buffalo Mountain Windfarm, eastern Tennessee and method(s) of observation, August 2001 - September 2003.

		Method of observation		
Scientific name	Common name	[a] Track plots	[b] Infrared Camera	[c] Other evidence
Canis latrans	coyote	X	X	X
Vulpes vulpes	red fox	X		
Procyon lotor	raccoon	X		X
Lynx rufus	bobcat	X		X
Felis catus	feral cat	X		
Crotalus horridus	timber rattlesnake			X
Agkistrodon contortrix	northern copperhead			X
Elaphe obsoleta	black ratsnake			X
Elaphe guttata	cornsnake			X
Peromyscus spp.	mouse species		X	
Corvus brachyrhynchos	American crow			X
Cathartes aura	turkey vulture			X
Coragyps atratus	black vulture			X

[a] Track plots were monitored during October and November 2001, and from April through August 2002.

[b] Motion-triggered cameras were used during September and October of 2002, and from May through August of 2003.

[c] Other evidence includes visual observation, scat, or tracks found outside of track plots and was collected during the full study period.

Table 15. Scavenging effects on search efficiency studies at Buffalo Mountain Windfarm, eastern Tennessee, September 2001 - July 2003.

Search efficiency study	Date conducted	Study carcasses taken within 12 hours	Average no. of days carcass remained	Planted carcasses showing signs of scavenging
I	9 Sep 2001	30%	16.7	-
II	18 Feb 2002	52%	3.2	28%
III	5 Aug 2002	52%	4.5	13%
IV	20 Sep 2002	48%	4.7	-
V	12 May 2003	14%	5.9	24%
VI	21 Jul 2003	24%	10.2	5%
Average of Trials		**36%**	**7.5**	**12%**
Average of all planted carcasses		**34%**	**6.3**	**6%**

Table 16. Non-fatal bat turbine collisions found at Buffalo Mountain Windfarm, eastern Tennessee, October 2000 - September 2003.

Date found	Species	Age	Sex	Injuries noted	Final status
3 Sep 2001	red bat	Adult	Female	Both wings bruised and broken	Euthanized on site
11 Jun 2002	big brown bat	Juvenile	Male	Broken wing with most of membrane missing	Euthanized on site
22 Jul 2002	hoary bat	Juvenile	Male	Right wing bruised and hemmoraged	Euthanized on site
8 Aug 2003	eastern pipistrelle	Juvenile	Male	Right wing bruised and hemmoraged, very weak	Euthanized on site
16 Sep 2003	red bat	Adult	Female	Left wing broken, weak	Euthanized on site

Table 17. Observed and adjusted number of bat fatalities and adjusted bat mortality rates for Buffalo Mountain Windfarm, eastern Tennessee, 2000-2003.

Year	No. bat mortalities	Adjusted no. bat mortalities	Adjusted bat mortality rate (No. fatalities / turbine / year)
1 Oct 2000 - 30 Sep 2001	29	59.96	19.99
1 Oct 2001 - 30 Sep 2002	39	58.47	19.49
1 Oct 2002 - 30 Sep 2003	46	68.96	22.99
Total	**114**	**187.39**	**20.82**

The estimated number of fatalities (m) during a given time period was calculated following methods presented by Johnson et al. (2003b): m = (N*I*C) / (k*t*p) where N is the total number of turbines, I is the interval between searches in days, C is the total number of carcasses found, k is the number of turbines sampled (3), t is the mean length of time carcasses remained on site before scavenged, and p is searcher efficiency.

Table 18. Overall search biases and mortality estimates for Buffalo Mountain Windfarm, eastern Tennessee, 2000-2003.

	Parameter estimate for BMW	Variance	SE	90% confidence interval
Searcher efficiency	0.37	0.1028	0.1309	(0.11, 0.63)
Scavenging removal time (days)	6.31	0.1930	0.1794	(5.95, 6.67)
Mortality rate estimate (# fatalities / turbine / year)	20.82	0.5833	0.4410	(19.53, 22.11)

Table 19. Average values of potential explanatory weather variables for nights with and without bat fatalities at Buffalo Mountain Windfarm, eastern Tennessee during 1 August – 15 September 2002 and 2003.

	No. Nights	Average nightly wind direction[a]	Average nightly windspeed (m/s)	Windspeed difference[b] (m/s)	Maximum nightly temperature (ºC)
Nights with bat fatalities	15	1.1	4.4	0.7	21.1
Nights without bat fatalities	37	0.5	5.3	1.3	22.6

[a] Calculated as a value between 0 (SW) and 2 (NE) (Beers et al. 1966).

[b] Difference between average windspeed during 1800 to 2400 hours and average. windspeed during 2400 to 0600 hours.

Table 20. List and scope of bat studies conducted at U.S. windfarms.

Windfarm	Scope of study Mortality	 Activity	Reference
Condon, CO		x	Hayes and Waldien 2000 as cited by Erickson et al. 2002
National Wind Technology Center, CO		x	Schmidt et al. 2003
Ponnequin, CO	x		Kerlinger et al. 2000
Buffalo Ridge Wind Resource Area, MN	x	x	Johnson et al. 2003a
Madison, NY	x		Kerlinger 2002
Klondike, OR	x		Johnson et al. 2003b
Vanscyle, OR	x		Erickson et al. 2000
Stateline, OR/WA	x	x	Erickson et al. 2002 and 2003a
Green Mountain, PA	x		Kerlinger 2002
Nine Canyon, WA	x		Erickson et al. 2003b
NE Wisconsin	x	x	Howe et al. 2002 as cited by Erickson et al. 2002
Mountaineer Wind Energy Center, WV	x		Kerns and Kerlinger 2004
Foote Creek Rim, WY	x	x	Gruver 2002, Johnson et al. 2003a

Table 21. Annual and seasonal bat activity index (AI) averages for the Buffalo Mountain Windfarm, eastern Tennessee, 2002-2003. AI was the proportion of one-minute increments in a night that contained one or more bat call sequences.

	2002			2003			2002 and 2003		
	No. nights (n)	Mean AI	SE	No. nights (n)	Mean AI	SE	No. nights (n)	Mean AI	SE
1 Apr - 15 May	22	3.48	1.37	18	2.20	0.70	40	2.91	0.81
16 May - 15 Jul	25	6.13	1.08	22	3.99	0.45	47	5.13	0.63
16 Jul - 30 Sep	57	16.50	1.68	43	12.16	1.70	100	14.63	1.22
Annual	104	11.25	1.15	83	7.84	1.03	187	9.74	0.79

Table 22. Bat activity index (AI, measured as proportion of one-minute increments containing one or more bat call sequences during a night) in relation to the presence of water and the presence of wind turbines at Buffalo Mountain Windfarm, eastern Tennessee, 2002-2003.

Apsect tested	No. paired locations	No. paired nights	Mean AI near water	Mean AI 150 m from water	Mean AI near water, onsite	Mean AI near water, offsite	Mean of paired differences	SE	P-value
Presence of water, onsite	1	77[a]	9.74	4.65			5.09	0.72	<0.0001[b]
Presence of wind turbines, near water	2	37[a]			9.26	3.44	5.82	1.83	0.0002
		22			8.05	22.90	-14.84	3.20	0.0001

[a] Data were transformed (Log+1) to meet normality assumptions, means and SE's are from original data.

[b] One-tailed test, Ha: bat activity onsite is greater near water than away from water.

Table 23. Paired nights of bat activity index (AI, measured as the proportion of one-minute increments that contained one or more bat call sequences during a night) at the Buffalo Mountain Windfarm, eastern Tennessee. Bat activity was recorded at ground level and two altitudes: 15 m and 70 m. All alternative hypotheses stated that ground-level bat activity was greater than bat activity at the stated altitude.

	No. paired nights (n)	Mean AI at ground	Mean AI at 15 m or 70 m	Mean of difference between pairs	SE	P-value	Power
Ground vs 15 m (Jun-Jul 2002)[a]	13	0.73	0.61	0.12	0.18	0.26	0.15
Ground vs 70 m (Aug-Oct 2002)[b]	28[d]	7.76	1.07	6.69	1.21	<0.0001	1.00
Ground vs 70 m (May-Jun 2003)[c]	9[d]	1.41	0.42	0.99	0.52	0.02	0.73

[a] 13 nights between 21 June and 7 July 2002.

[b] 28 nights between 2 August and 2 October 2002.

[c] 9 nights between 23 May and 29 June 2003.

[d] Data were transformed (log+1) to meet normality assumptions, means and SE's are from original data.

Table 24. Bat activity index (AI, measured at the proportion of one-minute increments containing one or more bat call sequences during a night) during two time frames: individual nights using only fresh fatalities, and search intervals using all fatalities during 16 July - 30 September, 2002 and 2003, Buffalo Mountain Windfarm, eastern Tennessee.

	n	Mean	SE	95% confidence interval	P-value*	Power
Individual nights						
Non-fatal nights	57	12.49	1.42	(9.66 - 15.32)	0.0067	0.81
Fatal nights	8	22.99	4.49	(12.37 - 33.61)		
Search intervals**						
Non-fatal intervals	18	12.61	2.30	(7.77 - 17.46)	0.15	0.09
Fatal intervals	20	16.31	2.46	(11.16 - 21.45)		

* P-values based on one tailed-tests with alternative hypotheses that bat activity was greater during fatality time periods.

** Data were transformed (Log+1) to satifisy normality assumptions, but statistical parameters (mean, SE, and 95% CI) are based on the original data.

Table 25. Proportion of monitored nights a bat species was acoustically identified two or more times at the Buffalo Mountain Windfarm pond site. Calls within a bat call sequence were assigned to one of twelve possible species using a discriminant function model. Only sequences with ≥ 75% of the calls assigned to the same species were considered. Results are presented for field seasons 2002 (136 nights) and 2003 (86 nights).

Species	**2002**	**2003**	**2002 and 2003 average**
eastern pipistrelle	31.6%	36.0%	33.8%
big brown bat	19.1%	9.3%	14.2%
red bat	12.5%	9.3%	10.9%
silver-haired bat	9.6%	2.2%	5.9%
hoary bat	2.2%	2.3%	2.3%
evening bat	3.7%	-	1.8%
gray bat*	-	-	-
little brown bat	-	-	-
Indiana bat	-	-	-
southeastern bat	-	-	-
northern long-eared bat	-	-	-
eastern small-footed bat	-	-	-

* Bat calls initially assigned to gray bat were visually analyzed for the distinctive gray bat call shape (E. Britzke, pers. comm.). All but one call sequence lacked the distinctive shape, therefore, gray bat did not meet criteriaa for confirmed presence.

Table 26. Percentages of monitored nights that a species was acoustically identified with two or more calls during three seasonal periods at the Buffalo Mountain Windfarm pond site, eastern Tennessee. N = number of complete nights of acoustical monitoring.

	1 April - 15 May			16 May - 15 July			16 July - 30 September		
Species	2002 (n = 23)	2003 (n = 17)	2002 & 2003 average (n = 40)	2002 (n = 26)	2003 (n = 24)	2002 & 2003 average (n = 60)	2002 (n = 60)	2003 (n = 45)	2002 & 2003 average (n = 105)
eastern pipistrelle	4.3%	11.8%	8.1%	23.1%	25.0%	24.0%	60.0%	51.1%	55.6%
big brown bat	4.3%	5.9%	5.1%	7.7%	0%	3.8%	38.3%	15.6%	26.9%
red bat	0%	0%	0%	11.5%	0%	5.8%	20.0%	17.8%	18.9%
silver-haired bat	17.4%	11.8%	14.6%	11.5%	0%	5.8%	6.7%	2.2%	4.4%
evening bat	0%	0%	0%	0%	0%	0%	8.3%	0%	4.2%
hoary bat	8.7%	5.9%	7.3%	0%	4.2%	2.1%	1.7%	0%	0.8%

Table 27. Bat mist-netting captures at Buffalo Mountain Windfarm, eastern Tennessee, 2002 and 2003.

	Pond		Patterson Ridge		Control Plot 3	All Locations
Species	2002 (n = 10 nights)	2003 (n = 3 nights)	2002 (n = 2 nights)	2003 (n = 1 night)	2002 (n = 2 nights)	2002 & 2003 (n = 18 nights)
red bat	26	8	1			35
northern long-eared bat	2		1		1	4
eastern pipistrelle	1		2	2		5
big brown bat	1		2			3
hoary bat	1	1				2
Total # bats captured	31	9	6	2	1	49
# Bats / Net / Hour	0.20	0.25	0.13	0.13	0.03	0.18

Table 28. Species composition of bats at the Buffalo Mountain Windfarm, eastern Tennessee, identified using three methods: turbine fatalities, mist-netting, and acoustical identification, 2001 - 2003.

	% turbine fatalities				% mist-netted			% monitored nights a species was acoustically identified more than once		
Common Name	2001 (n = 31)	2002 (n = 44)	2003 (n = 43)	all years (n=87)	2002 (n = 38)	2003 (n = 11)	both years (n = 49)	2002 (n=136 nights)	2003 (n=86 nights)	Average of both years
red bat	61.3%	70.5%	51.2%	61.0%	71.1%	72.7%	71.4%	12.5%	9.3%	10.9%
eastern pipistrelle	29.0%	6.8%	39.5%	24.6%	7.9%	18.2%	10.2%	31.6%	36.0%	33.8%
big brown bat	3.2%	2.3%		1.7%	7.9%		6.1%	19.1%	9.3%	14.2%
silver-haired bat	3.2%		2.3%	1.7%				9.6%	2.2%	5.9%
hoary bat	3.2%	20.5%	4.7%	10.2%	2.6%	9.1%	4.1%	2.2%	2.3%	2.3%
Seminole bat			2.3%	0.8%				*	*	*
northern long-eared bat					10.5%		8.2%			
evening bat								3.7%		1.8%

* Model used for acoustical identification used only 12 bat species, Seminole bat was not included as a possible option.

APPENDIX C

Appendix C. Locations and number of bat files recorded with Anabat bat detectors at Buffalo Mountain Windfarm, eastern Tennessee and calculated activity index (AI, proportion of one-minute increments containing one or more bat call sequences during a night), 2001-2003.

Location	Date	No. of minutes in night	No. bat files recorded	No. of one-minute increments with one or more bat files	Calculated Activity Index (AI)
Pond	26-Apr-2001	574	2	2	0.35
Pond	1-May-2001	564	5	5	0.89
Pond	3-May-2001	559	35	31	5.55
Pond	4-May-2001	557	25	23	4.13
Pond	8-May-2001	549	4	4	0.73
Pond	9-May-2001	547	2	2	0.37
Pond	10-May-2001	545	0	0	0
Pond	11-May-2001	543	17	16	2.95
Pond	15-May-2001	537	78	71	13.22
Pond	16-May-2001	535	51	50	9.35
Pond	18-May-2001	531	41	39	7.34
Pond	13-Jun-2001	503	34	33	6.56
Pond	14-Jun-2001	503	37	33	6.56
Pond	27-Jun-2001	503	8	7	1.39
Pond	28-Jun-2001	504	8	8	1.59
Pond	26-Jul-2001	536	222	133	24.81
Pond	27-Jul-2001	538	2	2	0.37
Pond	31-Aug-2001	611	9	9	1.47
Pond	1-Sep-2001	613	8	8	1.31
Pond	3-Sep-2001	617	3	3	0.49
Pond	4-Sep-2001	619	0	0	0
Pond	5-Sep-2001	622	16	15	2.41
Pond	6-Sep-2001	624	4	4	0.64
Pond	17-Sep-2001	650	102	88	13.54
Pond	18-Sep-2001	651	43	40	6.14
Pond	21-Sep-2001	659	71	63	9.56
Pond	22-Sep-2001	661	60	56	8.47
Pond	28-Sep-2001	674	11	11	1.63
Pond	29-Sep-2001	677	7	7	1.03
Pond	1-Oct-2001	682	47	46	6.74
Pond	5-Oct-2001	690	6	6	0.87
Pond	6-Oct-2001	693	0	0	0
Pond	8-Oct-2001	697	0	0	0
Pond	9-Oct-2001	699	0	0	0

Appendix C continued.

Location	Date	No. of minutes in night	No. bat files recorded	No. of one-minute increments with one or more bat files	Calculated Activity Index (AI)
Pond	10-Oct-2001	701	2	2	0.29
Pond	15-Oct-2001	712	4	4	0.56
Pond	16-Oct-2001	714	3	3	0.42
Pond	19-Oct-2001	721	19	19	2.64
Pond	20-Oct-2001	723	0	0	0
Pond	29-Oct-2001	741	0	0	0
Pond	30-Oct-2001	743	1	1	0.13
Pond	2-Nov-2001	749	0	0	0
Pond	3-Nov-2001	750	1	1	0.13
Pond	5-Nov-2001	754	2	2	0.27
Pond	6-Nov-2001	756	1	1	0.13
Pond	21-Nov-2001	780	0	0	0
Pond	22-Nov-2001	781	0	0	0
Pond	23-Nov-2001	782	0	0	0
Pond	24-Nov-2001	783	1	1	0.13
Pond	25-Nov-2001	785	1	1	0.13
Pond	1-Apr-2002	631	4	4	0.63
Pond	2-Apr-2002	629	0	0	0
Pond	3-Apr-2002	627	0	0	0
Pond	5-Apr-2002	622	2	2	0.32
Pond	8-Apr-2002	615	0	0	0
Pond	12-Apr-2002	606	5	4	0.66
Pond	13-Apr-2002	603	0	0	0
Pond	14-Apr-2002	601	0	0	0
Pond	19-Apr-2002	590	154	114	19.32
Pond	20-Apr-2002	588	174	139	23.64
Pond	22-Apr-2002	583	25	21	3.60
Pond	23-Apr-2002	581	24	22	3.79
Pond	29-Apr-2002	568	23	20	3.52
Pond	30-Apr-2002	566	7	6	1.06
Pond	1-May-2002	564	6	6	1.06
Pond	3-May-2002	560	15	12	2.14
Pond	4-May-2002	558	0	0	0
Pond	5-May-2002	556	0	0	0
Pond	9-May-2002	547	76	66	12.07
Pond	10-May-2002	545	20	18	3.30
Pond	14-May-2002	539	8	8	1.48
Pond	15-May-2002	537	0	0	0
Pond	16-May-2002	535	46	37	6.92
Pond	27-May-2002	519	14	12	2.31
Pond	28-May-2002	517	15	13	2.51

Appendix C continued.

Location	Date	No. of minutes in night	No. bat files recorded	No. of one-minute increments with one or more bat files	Calculated Activity Index (AI)
Pond	29-May-2002	516	55	43	8.33
Pond	30-May-2002	515	43	39	7.57
Pond	31-May-2002	514	59	50	9.73
Pond	3-Jun-2002	511	52	46	9.00
Pond	4-Jun-2002	510	5	5	0.98
Pond	6-Jun-2002	508	8	8	1.57
Pond	7-Jun-2002	508	18	17	3.35
Pond	8-Jun-2002	507	38	31	6.11
Pond	9-Jun-2002	506	42	38	7.51
Pond	10-Jun-2002	505	33	26	5.15
Pond	11-Jun-2002	504	36	33	6.55
Pond	21-Jun-2002	502	11	11	2.19
Pond	22-Jun-2002	503	9	7	1.39
Pond	23-Jun-2002	503	12	11	2.19
Pond	25-Jun-2002	503	10	9	1.79
Pond	30-Jun-2002	505	47	41	8.12
Pond	1-Jul-2002	505	32	28	5.54
Pond	2-Jul-2002	507	20	18	3.55
Pond	8-Jul-2002	511	44	41	8.02
Pond	9-Jul-2002	512	60	55	10.74
Pond	11-Jul-2002	514	24	22	4.28
Pond	15-Jul-2002	519	211	145	27.94
Pond	16-Jul-2002	521	108	77	14.78
Pond	17-Jul-2002	521	35	32	6.14
Pond	18-Jul-2002	523	10	9	1.72
Pond	19-Jul-2002	524	226	134	25.57
Pond	20-Jul-2002	526	292	178	33.84
Pond	24-Jul-2002	532	140	101	18.98
Pond	25-Jul-2002	534	163	133	24.91
Pond	30-Jul-2002	542	252	185	34.13
Pond	31-Jul-2002	544	210	161	29.60
Pond	1-Aug-2002	546	148	111	20.33
Pond	2-Aug-2002	548	122	99	18.07
Pond	3-Aug-2002	550	184	129	23.45
Pond	4-Aug-2002	551	209	135	24.50
Pond	5-Aug-2002	553	317	182	32.91
Pond	6-Aug-2002	556	26	26	4.68
Pond	7-Aug-2002	558	40	36	6.45
Pond	8-Aug-2002	560	59	53	9.46
Pond	9-Aug-2002	562	274	171	30.43
Pond	10-Aug-2002	564	343	225	39.89

Appendix C continued.

Location	Date	No. of minutes in night	No. bat files recorded	No. of one-minute increments with one or more bat files	Calculated Activity Index (AI)
Pond	14-Aug-2002	572	171	140	24.48
Pond	15-Aug-2002	574	249	186	32.40
Pond	16-Aug-2002	577	161	129	22.36
Pond	17-Aug-2002	579	255	195	33.68
Pond	18-Aug-2002	581	243	181	31.15
Pond	19-Aug-2002	583	517	325	55.75
Pond	20-Aug-2002	585	158	136	23.25
Pond	23-Aug-2002	592	369	254	42.91
Pond	24-Aug-2002	594	170	137	23.06
Pond	30-Aug-2002	608	74	69	11.35
Pond	31-Aug-2002	610	54	50	8.20
Pond	1-Sep-2002	612	377	193	31.54
Pond	4-Sep-2002	619	71	64	10.34
Pond	5-Sep-2002	622	55	48	7.72
Pond	6-Sep-2002	624	316	168	26.92
Pond	7-Sep-2002	626	66	60	9.58
Pond	8-Sep-2002	628	33	29	4.62
Pond	9-Sep-2002	631	28	28	4.44
Pond	10-Sep-2002	633	36	33	5.21
Pond	11-Sep-2002	636	59	52	8.18
Pond	12-Sep-2002	637	36	35	5.49
Pond	13-Sep-2002	640	17	16	2.50
Pond	14-Sep-2002	642	20	19	2.96
Pond	15-Sep-2002	645	129	89	13.80
Pond	16-Sep-2002	647	64	59	9.12
Pond	17-Sep-2002	649	71	62	9.55
Pond	18-Sep-2002	651	87	79	12.14
Pond	19-Sep-2002	654	28	27	4.13
Pond	20-Sep-2002	656	6	6	0.91
Pond	21-Sep-2002	659	18	18	2.73
Pond	22-Sep-2002	660	84	69	10.45
Pond	23-Sep-2002	663	65	58	8.75
Pond	24-Sep-2002	665	38	37	5.56
Pond	25-Sep-2002	668	5	5	0.75
Pond	27-Sep-2002	672	155	131	19.49
Pond	28-Sep-2002	674	65	55	8.16
Pond	29-Sep-2002	676	20	20	2.96
Pond	30-Sep-2002	679	28	27	3.98
Pond	1-Oct-2002	681	55	49	7.20
Pond	2-Oct-2002	683	21	21	3.07
Pond	4-Oct-2002	688	64	58	8.43

Appendix C continued.

Location	Date	No. of minutes in night	No. bat files recorded	No. of one-minute increments with one or more bat files	Calculated Activity Index (AI)
Pond	5-Oct-2002	690	95	84	12.17
Pond	7-Oct-2002	694	26	25	3.60
Pond	8-Oct-2002	696	9	9	1.29
Pond	9-Oct-2002	699	6	6	0.86
Pond	10-Oct-2002	701	4	4	0.57
Pond	11-Oct-2002	703	49	48	6.83
Pond	12-Oct-2002	706	52	48	6.80
Pond	14-Oct-2002	709	6	6	0.85
Pond	15-Oct-2002	712	0	0	0
Pond	16-Oct-2002	714	8	8	1.12
Pond	18-Oct-2002	718	0	0	0
Pond	19-Oct-2002	721	17	15	2.08
Pond	21-Oct-2002	724	24	24	3.31
Pond	22-Oct-2002	726	24	24	3.31
Pond	23-Oct-2002	728	30	26	3.57
Pond	26-Oct-2002	735	31	25	3.40
Pond	28-Oct-2002	739	13	11	1.49
Pond	29-Oct-2002	741	39	32	4.32
Pond	31-Oct-2002	744	1	1	0.13
Pond	1-Nov-2002	746	1	1	0.13
Pond	4-Nov-2002	752	2	2	0.27
Pond	5-Nov-2002	754	0	0	0
Pond	6-Nov-2002	756	0	0	0
Pond	7-Nov-2002	757	0	0	0
Pond	8-Nov-2002	759	0	0	0
Pond	13-Nov-2002	768	0	0	0
Pond	14-Nov-2002	770	0	0	0
Pond	18-Nov-2002	775	0	0	0
Pond	19-Nov-2002	776	0	0	0
Pond	25-Nov-2002	785	0	0	0
Pond	26-Nov-2002	786	0	0	0
Pond	27-Nov-2002	787	0	0	0
Pond	28-Nov-2002	788	0	0	0
Pond	29-Nov-2002	790	0	0	0
Pond	30-Nov-2002	790	0	0	0
Pond	1-Dec-2002	791	0	0	0
Pond	2-Dec-2002	792	0	0	0
Pond	3-Dec-2002	793	0	0	0
Pond	4-Dec-2002	794	0	0	0
Pond	5-Dec-2002	795	0	0	0
Pond	16-Dec-2002	800	0	0	0

Appendix C continued.

Location	Date	No. of minutes in night	No. bat files recorded	No. of one-minute increments with one or more bat files	Calculated Activity Index (AI)
Pond	17-Dec-2002	801	0	0	0
Pond	18-Dec-2002	801	0	0	0
Pond	19-Dec-2002	801	0	0	0
Pond	20-Dec-2002	801	0	0	0
Pond	30-Dec-2002	799	0	0	0
Pond	31-Dec-2002	799	0	0	0
Pond	4-Mar-2003	697	0	0	0
Pond	5-Mar-2003	695	0	0	0
Pond	6-Mar-2003	692	0	0	0
Pond	7-Mar-2003	690	0	0	0
Pond	8-Mar-2003	688	0	0	0
Pond	9-Mar-2003	685	0	0	0
Pond	10-Mar-2003	683	0	0	0
Pond	11-Mar-2003	680	0	0	0
Pond	12-Mar-2003	678	4	7	1.03
Pond	13-Mar-2003	677	1	1	0.15
Pond	19-Mar-2003	662	0	0	0
Pond	20-Mar-2003	660	1	1	0.15
Pond	21-Mar-2003	658	1	1	0.15
Pond	22-Mar-2003	655	0	0	0
Pond	23-Mar-2003	653	0	0	0
Pond	24-Mar-2003	651	3	3	0.46
Pond	25-Mar-2003	648	6	6	0.93
Pond	26-Mar-2003	646	0	0	0
Pond	27-Mar-2003	643	4	4	0.62
Pond	28-Mar-2003	642	1	1	0.16
Pond	29-Mar-2003	639	0	0	0
Pond	3-Apr-2003	627	5	7	1.12
Pond	4-Apr-2003	624	1	1	0.16
Pond	7-Apr-2003	618	0	0	0
Pond	14-Apr-2003	602	18	18	2.99
Pond	17-Apr-2003	595	1	2	0.34
Pond	18-Apr-2003	593	8	8	1.35
Pond	22-Apr-2003	583	5	5	0.86
Pond	23-Apr-2003	581	6	8	1.38
Pond	25-Apr-2003	578	5	5	0.87
Pond	26-Apr-2003	575	1	1	0.17
Pond	28-Apr-2003	571	31	32	5.60
Pond	29-Apr-2003	569	8	8	1.41
Pond	1-May-2003	564	5	5	0.89
Pond	8-May-2003	550	35	37	6.73

Appendix C continued.

Location	Date	No. of minutes in night	No. bat files recorded	No. of one-minute increments with one or more bat files	Calculated Activity Index (AI)
Pond	9-May-2003	549	64	75	13.66
Pond	12-May-2003	543	7	7	1.29
Pond	13-May-2003	541	17	21	3.88
Pond	14-May-2003	539	6	6	1.11
Pond	30-May-2003	515	31	33	6.41
Pond	31-May-2003	514	8	8	1.56
Pond	3-Jun-2003	511	21	23	4.50
Pond	6-Jun-2003	508	3	3	0.59
Pond	7-Jun-2003	508	21	21	4.13
Pond	9-Jun-2003	506	11	11	2.17
Pond	10-Jun-2003	506	42	47	9.29
Pond	12-Jun-2003	504	32	36	7.14
Pond	13-Jun-2003	504	9	9	1.79
Pond	14-Jun-2003	503	15	17	3.38
Pond	19-Jun-2003	502	17	19	3.78
Pond	20-Jun-2003	502	7	7	1.39
Pond	23-Jun-2003	503	10	10	1.99
Pond	24-Jun-2003	503	14	15	2.98
Pond	2-Jul-2003	507	25	27	5.33
Pond	3-Jul-2003	507	20	20	3.94
Pond	7-Jul-2003	510	39	42	8.24
Pond	8-Jul-2003	511	24	27	5.28
Pond	10-Jul-2003	513	13	16	3.12
Pond	11-Jul-2003	514	25	28	5.45
Pond	14-Jul-2003	517	23	29	5.61
Pond	15-Jul-2003	519	37	40	7.71
Pond	16-Jul-2003	519	38	50	9.63
Pond	17-Jul-2003	521	13	17	3.26
Pond	18-Jul-2003	523	26	26	4.97
Pond	21-Jul-2003	527	6	6	1.14
Pond	22-Jul-2003	528	16	16	3.03
Pond	25-Jul-2003	534	21	24	4.49
Pond	26-Jul-2003	535	37	37	6.92
Pond	31-Jul-2003	544	82	93	17.10
Pond	1-Aug-2003	546	41	44	8.06
Pond	2-Aug-2003	548	22	22	4.01
Pond	5-Aug-2003	553	89	102	18.44
Pond	6-Aug-2003	555	96	115	20.72
Pond	8-Aug-2003	560	40	46	8.21
Pond	9-Aug-2003	562	52	58	10.32

Appendix C continued.

Location	Date	No. of minutes in night	No. bat files recorded	No. of one-minute increments with one or more bat files	Calculated Activity Index (AI)
Pond	12-Aug-2003	567	55	57	10.05
Pond	13-Aug-2003	569	93	99	17.40
Pond	15-Aug-2003	574	110	128	22.30
Pond	16-Aug-2003	576	109	136	23.61
Pond	17-Aug-2003	579	140	168	29.02
Pond	19-Aug-2003	582	52	61	10.48
Pond	20-Aug-2003	584	246	323	55.31
Pond	21-Aug-2003	587	247	328	55.88
Pond	22-Aug-2003	589	239	353	59.93
Pond	23-Aug-2003	592	81	88	14.86
Pond	26-Aug-2003	598	185	216	36.12
Pond	27-Aug-2003	600	141	164	27.33
Pond	28-Aug-2003	603	124	133	22.06
Pond	29-Aug-2003	605	103	115	19.01
Pond	30-Aug-2003	607	161	197	32.45
Pond	2-Sep-2003	614	59	64	10.42
Pond	3-Sep-2003	616	31	30	4.87
Pond	5-Sep-2003	621	40	41	6.60
Pond	6-Sep-2003	623	36	38	6.10
Pond	16-Sep-2003	646	16	16	2.48
Pond	17-Sep-2003	648	15	15	2.31
Pond	18-Sep-2003	651	53	58	8.91
Pond	19-Sep-2003	653	28	31	4.75
Pond	20-Sep-2003	656	21	22	3.35
Pond	21-Sep-2003	657	7	7	1.07
Pond	23-Sep-2003	662	20	22	3.32
Pond	24-Sep-2003	665	40	43	6.47
Pond	26-Sep-2003	669	8	8	1.20
Pond	27-Sep-2003	671	26	27	4.02
Turbine 1 Base	22-Sep-2001	661	2	2	0.30
Turbine 1 Base	24-Sep-2001	665	1	1	0.15
Turbine 1 Base	25-Sep-2001	668	1	1	0.15
Turbine 1 Base	10-Oct-2001	701	12	10	1.43
Turbine 1 Base	11-Oct-2001	704	5	5	0.71
Turbine 1 Base	15-Oct-2001	712	4	4	0.56
Turbine 1 Base	19-Oct-2001	721	6	6	0.83
Turbine 1 Base	20-Oct-2001	723	3	3	0.41
Turbine 1 Base	26-Apr-2002	691	35	32	4.63
Turbine 1 Base	22-May-2002	645	1	1	0.16
Turbine 1 Base	23-May-2002	645	1	1	0.16

Appendix C continued.

Location	Date	No. of minutes in night	No. bat files recorded	No. of one-minute increments with one or more bat files	Calculated Activity Index (AI)
Turbine 1 Base	24-May-2002	643	14	14	2.18
Turbine 1 Base	25-May-2002	642	12	11	1.71
Turbine 1 Base	26-May-2002	641	5	5	0.78
Turbine 1 Base	3-Jun-2002	632	16	16	2.53
Turbine 1 Base	4-Jun-2002	632	4	4	0.63
Turbine 1 Base	10-Jun-2002	627	4	4	0.64
Turbine 1 Base	11-Jun-2002	627	7	7	1.12
Turbine 1 Base	12-Jun-2002	627	18	17	2.71
Turbine 1 Base	13-Jun-2002	626	8	7	1.12
Turbine 1 Base	14-Jun-2002	626	5	5	0.80
Turbine 1 Base	18-Jun-2002	624	4	4	0.64
Turbine 1 Base	19-Jun-2002	625	3	3	0.48
Turbine 1 Base	20-Jun-2002	625	6	6	0.96
Turbine 1 Base	23-Jul-2002	649	53	48	7.40
Turbine 1 Base	24-Jul-2002	651	62	57	8.76
Turbine 1 Base	25-Jul-2002	653	95	86	13.17
Turbine 1 Base	26-Jul-2002	653	115	101	15.47
Turbine 1 Base	27-Jul-2002	655	70	64	9.77
Turbine 1 Base	1-Aug-2002	663	58	53	7.99
Turbine 1 Base	2-Aug-2002	665	29	25	3.76
Turbine 1 Base	5-Aug-2002	670	53	47	7.01
Turbine 1 Base	6-Aug-2002	672	0	0	0.00
Turbine 1 Base	7-Aug-2002	674	1	1	0.15
Turbine 1 Base	8-Aug-2002	676	15	15	2.22
Turbine 1 Base	11-Aug-2002	681	25	24	3.52
Turbine 1 Base	12-Aug-2002	684	64	60	8.77
Turbine 1 Base	13-Aug-2002	685	47	45	6.57
Turbine 1 Base	14-Aug-2002	687	79	70	10.19
Turbine 1 Base	15-Aug-2002	689	113	87	12.63
Turbine 1 Base	16-Aug-2002	691	85	80	11.58
Turbine 1 Base	17-Aug-2002	693	102	92	13.28
Turbine 1 Base	18-Aug-2002	695	78	72	10.36
Turbine 1 Base	23-Aug-2002	705	152	127	18.01
Turbine 1 Base	24-Aug-2002	707	58	55	7.78
Turbine 1 Base	30-Aug-2002	720	31	31	4.31
Turbine 1 Base	31-Aug-2002	722	36	35	4.85
Turbine 1 Base	1-Sep-2002	724	43	40	5.52
Turbine 1 Base	2-Sep-2002	727	0	0	0.00
Turbine 1 Base	3-Sep-2002	728	171	121	16.62
Turbine 1 Base	4-Sep-2002	731	60	57	7.80

Appendix C continued.

Location	Date	No. of minutes in night	No. bat files recorded	No. of one-minute increments with one or more bat files	Calculated Activity Index (AI)
Turbine 1 Base	6-Sep-2002	735	41	35	4.76
Turbine 1 Base	7-Sep-2002	738	23	23	3.12
Turbine 1 Base	8-Sep-2002	740	31	30	4.05
Turbine 1 Base	9-Sep-2002	742	19	18	2.43
Turbine 1 Base	10-Sep-2002	744	29	28	3.76
Turbine 1 Base	11-Sep-2002	747	67	65	8.70
Turbine 1 Base	13-Sep-2002	750	11	11	1.47
Turbine 1 Base	14-Sep-2002	753	10	10	1.33
Turbine 1 Base	15-Sep-2002	755	30	25	3.31
Turbine 1 Base	16-Sep-2002	758	25	25	3.30
Turbine 1 Base	17-Sep-2002	759	59	56	7.38
Turbine 1 Base	19-Sep-2002	764	17	17	2.23
Turbine 1 Base	20-Sep-2002	767	5	5	0.65
Turbine 1 Base	22-Sep-2002	771	27	27	3.50
Turbine 1 Base	23-Sep-2002	773	27	26	3.36
Turbine 1 Base	27-Sep-2002	782	205	154	19.69
Turbine 1 Base	28-Sep-2002	785	51	49	6.24
Turbine 1 Base	30-Sep-2002	789	18	18	2.28
Turbine 1 Base	1-Oct-2002	791	14	14	1.77
Turbine 1 Base	2-Oct-2002	793	7	6	0.76
Turbine 1 Base	1-Apr-2003	744	1	1	0.13
Turbine 1 Base	3-Apr-2003	740	3	3	0.41
Turbine 1 Base	4-Apr-2003	737	2	2	0.27
Turbine 1 Base	5-Apr-2003	735	2	2	0.27
Turbine 1 Base	6-Apr-2003	732	0	0	0.00
Turbine 1 Base	7-Apr-2003	731	16	14	1.92
Turbine 1 Base	22-Apr-2003	698	2	2	0.29
Turbine 1 Base	23-Apr-2003	696	4	4	0.57
Turbine 1 Base	24-Apr-2003	694	1	1	0.14
Turbine 1 Base	25-Apr-2003	693	3	3	0.43
Turbine 1 Base	26-Apr-2003	691	0	0	0.00
Turbine 1 Base	28-Apr-2003	686	34	33	4.81
Turbine 1 Base	29-Apr-2003	684	9	8	1.17
Turbine 1 Base	1-May-2003	681	6	6	0.88
Turbine 1 Base	2-May-2003	679	1	1	0.15
Turbine 1 Base	8-May-2003	668	24	23	3.44
Turbine 1 Base	9-May-2003	666	41	36	5.41
Turbine 1 Base	12-May-2003	660	5	5	0.76
Turbine 1 Base	13-May-2003	660	6	6	0.91
Turbine 1 Base	14-May-2003	658	4	4	0.61

Appendix C continued.

Location	Date	No. of minutes in night	No. bat files recorded	No. of one-minute increments with one or more bat files	Calculated Activity Index (AI)
Turbine 1 Base	15-May-2003	656	26	25	3.81
Turbine 1 Base	16-May-2003	654	27	26	3.98
Turbine 1 Base	19-May-2003	650	6	6	0.92
Turbine 1 Base	20-May-2003	648	4	4	0.62
Turbine 1 Base	21-May-2003	647	8	8	1.24
Turbine 1 Base	23-May-2003	645	2	2	0.31
Turbine 1 Base	24-May-2003	643	5	5	0.78
Turbine 1 Base	25-May-2003	642	1	1	0.16
Turbine 1 Base	27-May-2003	640	2	2	0.31
Turbine 1 Base	28-May-2003	638	23	23	3.61
Turbine 1 Base	29-May-2003	637	1	1	0.16
Turbine 1 Base	16-Jun-2003	625	7	7	1.12
Turbine 1 Base	17-Jun-2003	625	15	15	2.40
Turbine 1 Base	18-Jun-2003	624	9	9	1.44
Turbine 1 Base	23-Jun-2003	625	4	4	0.64
Turbine 1 Base	24-Jun-2003	625	5	5	0.80
Turbine 1 Base	25-Jun-2003	625	10	9	1.44
Turbine 1 Base	26-Jun-2003	625	3	3	0.48
Turbine 1 Base	27-Jun-2003	626	6	6	0.96
Turbine 1 Base	28-Jun-2003	626	15	15	2.40
Turbine 1 Base	29-Jun-2003	627	10	10	1.59
Turbine 1 Base	30-Jun-2003	627	2	2	0.32
Turbine 1 Base	1-Jul-2003	628	0	0	0.00
Turbine 1 Base	2-Jul-2003	628	6	6	0.96
Turbine 1 Base	3-Jul-2003	628	16	14	2.23
Turbine 1 Base	4-Jul-2003	629	23	23	3.66
Turbine 1 Base	10-Jul-2003	634	3	3	0.47
Turbine 1 Base	11-Jul-2003	635	7	7	1.10
Turbine 1 Base	12-Jul-2003	636	2	2	0.31
Turbine 1 Base	14-Jul-2003	638	19	19	2.98
Turbine 1 Base	15-Jul-2003	639	29	28	4.38
Turbine 1 Base	16-Jul-2003	640	15	15	2.34
Turbine 1 Base	17-Jul-2003	642	11	11	1.71
Turbine 1 Base	18-Jul-2003	643	4	4	0.62
Turbine 1 Base	19-Jul-2003	644	6	6	0.93
Turbine 1 Base	21-Jul-2003	647	3	3	0.46
Turbine 1 Base	22-Jul-2003	648	8	8	1.23
Turbine 1 Base	23-Jul-2003	649	16	15	2.31
Turbine 1 Base	24-Jul-2003	651	10	9	1.38
Turbine 1 Base	25-Jul-2003	653	7	7	1.07

Appendix C continued.

Location	Date	No. of minutes in night	No. bat files recorded	No. of one-minute increments with one or more bat files	Calculated Activity Index (AI)
Turbine 1 Base	26-Jul-2003	653	11	11	1.68
Turbine 1 Base	27-Jul-2003	655	15	15	2.29
Turbine 1 Base	28-Jul-2003	657	4	4	0.61
Turbine 1 Base	29-Jul-2003	659	16	16	2.43
Turbine 1 Base	30-Jul-2003	660	22	21	3.18
Turbine 1 Base	12-Aug-2003	684	12	11	1.61
Turbine 1 Base	13-Aug-2003	685	38	37	5.40
Turbine 1 Base	14-Aug-2003	687	72	68	9.90
Turbine 1 Base	2-Sep-2003	727	44	41	5.64
Turbine 1 Base	3-Sep-2003	728	7	7	0.96
Turbine 1 Base	4-Sep-2003	731	28	27	3.69
Turbine 1 Base	5-Sep-2003	733	33	32	4.37
Turbine 1 Base	6-Sep-2003	735	30	30	4.08
Turbine 1 Base	7-Sep-2003	738	50	46	6.23
Turbine 1 Base	23-Sep-2003	773	12	12	1.55
Turbine 1 Base	24-Sep-2003	776	10	10	1.29
Turbine 1 Base	26-Sep-2003	780	0	0	0.00
Turbine 1 Base	27-Sep-2003	782	0	0	0.00
Base of 15 m pole	21-Jun-2002	625	1	1	0.16
Base of 15 m pole	22-Jun-2002	624	0	0	0.00
Base of 15 m pole	25-Jun-2002	625	3	3	0.48
Base of 15 m pole	26-Jun-2002	625	3	3	0.48
Base of 15 m pole	27-Jun-2002	626	1	1	0.16
Base of 15 m pole	28-Jun-2002	626	1	1	0.16
Base of 15 m pole	29-Jun-2002	627	2	2	0.32
Base of 15 m pole	30-Jun-2002	627	19	17	2.71
Base of 15 m pole	3-Jul-2002	628	0	0	0.00
Base of 15 m pole	4-Jul-2002	629	0	0	0.00
Base of 15 m pole	5-Jul-2002	629	6	6	0.95
Base of 15 m pole	6-Jul-2002	631	3	3	0.48
Base of 15 m pole	7-Jul-2002	632	11	11	1.74
Top of 15 m pole	21-Jun-2002	625	1	1	0.16
Top of 15 m pole	22-Jun-2002	624	1	1	0.16
Top of 15 m pole	25-Jun-2002	625	0	0	0.00
Top of 15 m pole	26-Jun-2002	625	6	5	0.80
Top of 15 m pole	27-Jun-2002	626	1	1	0.16
Top of 15 m pole	28-Jun-2002	626	4	4	0.64
Top of 15 m pole	29-Jun-2002	627	5	5	0.80
Top of 15 m pole	30-Jun-2002	627	10	10	1.59
Top of 15 m pole	3-Jul-2002	628	1	1	0.16

Appendix C continued.

Location	Date	No. of minutes in night	No. bat files recorded	No. of one-minute increments with one or more bat files	Calculated Activity Index (AI)
Top of 15 m pole	4-Jul-2002	629	3	3	0.48
Top of 15 m pole	5-Jul-2002	629	3	3	0.48
Top of 15 m pole	6-Jul-2002	631	1	1	0.16
Top of 15 m pole	7-Jul-2002	632	5	5	0.79
Turbine Top	2-Aug-2002	665	11	11	1.65
Turbine Top	3-Aug-2002	667	5	3	0.45
Turbine Top	4-Aug-2002	668	13	10	1.50
Turbine Top	5-Aug-2002	670	5	5	0.75
Turbine Top	6-Aug-2002	672	3	3	0.45
Turbine Top	7-Aug-2002	674	4	3	0.45
Turbine Top	8-Aug-2002	676	5	5	0.74
Turbine Top	9-Aug-2002	677	6	6	0.89
Turbine Top	10-Aug-2002	679	0	0	0.00
Turbine Top	11-Aug-2002	681	12	12	1.76
Turbine Top	12-Aug-2002	684	5	5	0.73
Turbine Top	13-Aug-2002	685	3	3	0.44
Turbine Top	14-Aug-2002	687	5	3	0.44
Turbine Top	15-Aug-2002	689	7	7	1.02
Turbine Top	16-Aug-2002	691	4	4	0.58
Turbine Top	17-Aug-2002	693	10	9	1.30
Turbine Top	23-Aug-2002	705	14	14	1.99
Turbine Top	24-Aug-2002	707	34	29	4.10
Turbine Top	25-Aug-2002	710	18	17	2.39
Turbine Top	26-Aug-2002	712	10	9	1.26
Turbine Top	27-Aug-2002	713	5	5	0.70
Turbine Top	28-Aug-2002	716	2	2	0.28
Turbine Top	29-Aug-2002	718	3	3	0.42
Turbine Top	30-Aug-2002	720	4	4	0.56
Turbine Top	31-Aug-2002	722	7	7	0.97
Turbine Top	1-Sep-2002	724	8	6	0.83
Turbine Top	2-Sep-2002	727	4	4	0.55
Turbine Top	3-Sep-2002	728	3	3	0.41
Turbine Top	4-Sep-2002	731	8	8	1.09
Turbine Top	19-Sep-2002	764	1	1	0.13
Turbine Top	20-Sep-2002	767	0	0	0.00
Turbine Top	21-Sep-2002	769	0	0	0.00
Turbine Top	22-Sep-2002	771	2	2	0.26
Turbine Top	23-Sep-2002	773	14	14	1.81
Turbine Top	24-Sep-2002	776	6	6	0.77
Turbine Top	25-Sep-2002	778	0	0	0.00

Appendix C continued.

Location	Date	No. of minutes in night	No. bat files recorded	No. of one-minute increments with one or more bat files	Calculated Activity Index (AI)
Turbine Top	26-Sep-2002	780	1	1	0.13
Turbine Top	27-Sep-2002	782	7	7	0.90
Turbine Top	28-Sep-2002	785	5	5	0.64
Turbine Top	29-Sep-2002	787	2	2	0.25
Turbine Top	30-Sep-2002	789	0	0	0.00
Turbine Top	1-Oct-2002	791	2	2	0.25
Turbine Top	2-Oct-2002	793	3	3	0.38
Turbine Top	3-Oct-2002	796	1	1	0.13
Turbine Top	4-Oct-2002	798	1	1	0.13
Turbine Top	5-Oct-2002	801	3	3	0.37
Turbine Top	6-Oct-2002	802	2	2	0.25
Turbine Top	28-Oct-2002	850	0	0	0.00
Turbine Top	29-Oct-2002	852	0	0	0.00
Turbine Top	30-Oct-2002	854	0	0	0.00
Turbine Top	31-Oct-2002	856	0	0	0.00
Turbine Top	1-Nov-2002	858	0	0	0.00
Turbine Top	2-Nov-2002	860	0	0	0.00
Turbine Top	3-Nov-2002	862	0	0	0.00
Turbine Top	4-Nov-2002	864	2	1	0.12
Turbine Top	5-Nov-2002	866	0	0	0.00
Turbine Top	6-Nov-2002	868	0	0	0.00
Turbine Top	7-Nov-2002	870	0	0	0.00
Turbine Top	8-Nov-2002	872	0	0	0.00
Turbine Top	9-Nov-2002	874	0	0	0.00
Turbine Top	10-Nov-2002	875	0	0	0.00
Turbine Top	11-Nov-2002	877	1	1	0.11
Turbine Top	12-Nov-2002	879	0	0	0.00
Turbine Top	13-Nov-2002	881	0	0	0.00
Turbine Top	14-Nov-2002	882	0	0	0.00
Turbine Top	15-Nov-2002	884	0	0	0.00
Turbine Top	16-Nov-2002	886	0	0	0.00
Turbine Top	17-Nov-2002	887	0	0	0.00
Turbine Top	18-Nov-2002	889	0	0	0.00
Turbine Top	19-Nov-2002	890	0	0	0.00
Turbine Top	20-Nov-2002	892	0	0	0.00
Turbine Top	21-Nov-2002	893	0	0	0.00
Turbine Top	22-Nov-2002	895	0	0	0.00
Turbine Top	23-Nov-2002	896	0	0	0.00
Turbine Top	24-Nov-2002	898	0	0	0.00
Turbine Top	15-Apr-2003	713	0	0	0.00

Appendix C continued.

Location	Date	No. of minutes in night	No. bat files recorded	No. of one-minute increments with one or more bat files	Calculated Activity Index (AI)
Turbine Top	16-Apr-2003	711	1	1	0.14
Turbine Top	17-Apr-2003	709	0	0	0.00
Turbine Top	18-Apr-2003	706	1	1	0.14
Turbine Top	23-May-2003	645	0	0	0.00
Turbine Top	24-May-2003	643	2	2	0.31
Turbine Top	25-May-2003	642	0	0	0.00
Turbine Top	26-May-2003	641	0	0	0.00
Turbine Top	27-May-2003	640	0	0	0.00
Turbine Top	28-May-2003	638	0	0	0.00
Turbine Top	29-May-2003	637	0	0	0.00
Turbine Top	30-May-2003	636	0	0	0.00
Turbine Top	31-May-2003	635	2	2	0.31
Turbine Top	1-Jun-2003	634	1	1	0.16
Turbine Top	2-Jun-2003	633	0	0	0.00
Turbine Top	3-Jun-2003	632	0	0	0.00
Turbine Top	4-Jun-2003	632	0	0	0.00
Turbine Top	5-Jun-2003	631	0	0	0.00
Turbine Top	6-Jun-2003	631	0	0	0.00
Turbine Top	7-Jun-2003	629	8	8	1.27
Turbine Top	8-Jun-2003	628	0	0	0.00
Turbine Top	9-Jun-2003	628	4	4	0.64
Turbine Top	10-Jun-2003	627	1	1	0.16
Turbine Top	27-Jun-2003	626	11	10	1.60
Turbine Top	28-Jun-2003	626	3	3	0.48
Turbine Top	29-Jun-2003	627	4	4	0.64
Turbine Top	1-Aug-2003	663	1	1	0.15
Turbine Top	2-Aug-2003	665	3	3	0.45
Turbine Top	29-Aug-2003	718	4	4	0.56
Turbine Top	30-Aug-2003	720	6	5	0.69
Control plot 3	26-Apr-2002	691	0	0	0.00
Control plot 3	27-Apr-2002	688	0	0	0.00
Control plot 3	28-Apr-2002	686	0	0	0.00
Control plot 3	29-Apr-2002	684	5	5	0.73
Control plot 3	30-Apr-2002	682	3	3	0.44
Control plot 3	3-May-2002	677	8	8	1.18
Control plot 3	4-May-2002	675	1	1	0.15
Control plot 3	5-May-2002	673	20	17	2.53
Control plot 3	6-May-2002	671	2	2	0.30
Control plot 3	7-May-2002	669	46	44	6.58
Control plot 3	9-May-2002	666	143	108	16.22

Appendix C continued.

Location	Date	No. of minutes in night	No. bat files recorded	No. of one-minute increments with one or more bat files	Calculated Activity Index (AI)
Control plot 3	10-May-2002	664	112	89	13.40
Control plot 3	11-May-2002	662	25	21	3.17
Control plot 3	12-May-2002	660	5	5	0.76
Control plot 3	14-May-2002	658	0	0	0.00
Control plot 3	15-May-2002	656	9	9	1.37
Control plot 3	16-May-2002	654	11	10	1.53
Control plot 3	17-May-2002	653	2	2	0.31
Control plot 3	23-Jul-2002	649	42	28	4.31
Control plot 3	24-Jul-2002	651	27	24	3.69
Control plot 3	25-Jul-2002	653	42	40	6.13
Control plot 3	26-Jul-2002	653	55	52	7.96
Control plot 3	27-Jul-2002	655	38	37	5.65
Control plot 3	28-Jul-2002	657	103	90	13.70
Control plot 3	29-Jul-2002	659	64	58	8.80
Control plot 3	30-Jul-2002	660	47	38	5.76
Control plot 3	31-Jul-2002	661	19	13	1.97
Control plot 3	28-Oct-2002	850	0	0	0.00
Control plot 3	29-Oct-2002	852	14	14	1.64
Control plot 3	31-Oct-2002	856	0	0	0.00
Control plot 3	1-Apr-2003	744	0	0	0.00
Control plot 3	7-Apr-2003	731	0	0	0.00
Control plot 3	22-Apr-2003	698	0	0	0.00
Control plot 3	23-Apr-2003	696	0	0	0.00
Control plot 3	25-Apr-2003	693	0	0	0.00
Control plot 3	26-Apr-2003	691	0	0	0.00
Control plot 3	1-May-2003	681	0	0	0.00
Control plot 3	2-May-2003	679	0	0	0.00
Control plot 3	30-May-2003	636	5	5	0.79
Control plot 3	31-May-2003	635	2	2	0.31
Control plot 3	1-Jun-2003	634	4	4	0.63
Control plot 3	3-Jun-2003	632	8	8	1.27
Control plot 3	4-Jun-2003	632	0	0	0.00
Control plot 3	5-Jun-2003	631	4	4	0.63
Control plot 3	6-Jun-2003	631	1	1	0.16
Control plot 3	7-Jun-2003	629	17	16	2.54
Control plot 3	8-Jun-2003	628	7	7	1.11
Control plot 3	9-Jun-2003	628	13	12	1.91
Control plot 3	10-Jun-2003	627	8	8	1.28
Control plot 3	11-Jun-2003	627	6	6	0.96
Control plot 3	18-Aug-2003	695	38	30	4.32
Control plot 3	19-Aug-2003	697	58	50	7.17

Appendix C continued.

Location	Date	No. of minutes in night	No. bat files recorded	No. of one-minute increments with one or more bat files	Calculated Activity Index (AI)
Control plot 3	20-Aug-2003	699	48	44	6.29
Control plot 3	21-Aug-2003	701	75	63	8.99
Control plot 3	22-Aug-2003	704	82	65	9.23
Control plot 3	23-Aug-2003	705	32	32	4.54
Control plot 3	12-Sep-2003	749	11	11	1.47
Control plot 3	13-Sep-2003	750	11	11	1.47
Control plot 3	16-Sep-2003	758	7	6	0.79
Control plot 3	17-Sep-2003	759	8	5	0.66
Control plot 3	19-Sep-2003	764	11	11	1.44
Control plot 3	20-Sep-2003	767	4	4	0.52
Control plot 3	21-Sep-2003	769	2	2	0.26
Control plot 3	22-Sep-2003	771	5	5	0.65
Patterson Ridge	6-Jun-2002	631	27	23	3.65
Patterson Ridge	7-Jun-2002	629	43	31	4.93
Patterson Ridge	8-Jun-2002	628	60	41	6.53
Patterson Ridge	9-Jun-2002	628	124	84	13.38
Patterson Ridge	10-Jun-2002	627	346	261	41.63
Patterson Ridge	13-Jun-2002	626	216	210	33.55
Patterson Ridge	14-Jun-2002	626	18	13	2.08
Patterson Ridge	15-Jun-2002	625	7	4	0.64
Patterson Ridge	16-Jun-2002	625	6	5	0.80
Patterson Ridge	8-Jul-2002	632	435	252	39.87
Patterson Ridge	9-Jul-2002	633	382	210	33.18
Patterson Ridge	15-Jul-2002	639	135	93	14.55
Patterson Ridge	16-Jul-2002	640	127	96	15.00
Patterson Ridge	17-Jul-2002	642	135	94	14.64
Patterson Ridge	19-Jul-2002	644	128	86	13.35
Patterson Ridge	20-Jul-2002	645	502	271	42.02
Patterson Ridge	21-Jul-2002	647	417	339	52.40
Patterson Ridge	7-Oct-2002	804	191	135	16.79
Patterson Ridge	8-Oct-2002	807	461	262	32.47
Patterson Ridge	9-Oct-2002	809	281	164	20.27
Patterson Ridge	10-Oct-2002	812	159	98	12.07
Patterson Ridge	11-Oct-2002	814	334	220	27.03
Patterson Ridge	12-Oct-2002	816	295	201	24.63
Patterson Ridge	14-Oct-2002	820	116	97	11.83
Patterson Ridge	18-Oct-2002	829	16	13	1.57
Patterson Ridge	19-Oct-2002	831	79	64	7.70
Patterson Ridge	23-Oct-2002	839	299	185	22.05
Patterson Ridge	24-Oct-2002	841	68	60	7.13
Patterson Ridge	25-Oct-2002	844	9	9	1.07

VITA

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