Assessment And Prediction Of Bird And Bat Mortality At Wind Energy Facilities In The Southeastern United States

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ABSTRACT

Mortality of birds at windfarms has been an area of concern since the first commercial windfarms were constructed in the 1970s. More recently, concern over bat mortality at windfarms has emerged. Studies of avian and bat mortality from midwestern and western North America show regional variation in mortality rates and species affected. We describe the results of a study of bird and bat activity and mortality at the Tennessee Valley Authority's 3-turbine Buffalo Mountain Windfarm in eastern Tennessee, the first commercial windfarm in the southeastern United States.

Mortality of both birds and bats was determined by regular carcass searches from the fall of 2000, when the windfarm began commercial operation, through the fall of 2003. Avian activity was determined by visual observations of migrating raptors during the fall of 2001, by mist-netting birds during the fall of 2001 and 2002, and by analysis of regional migration as detected by NEXRAD radar imagery during the spring and fall of 2001 and 2002. Efforts to monitor nocturnal bird migration through the area with acoustic recording equipment were unsuccessful. Bat activity was determined by the continuous operation of electronic bat detectors and by periodic mist-netting in the windfarm area.

The avian mortality rate, adjusted for search efficiency and carcass scavenging biases, was 7.27 birds/turbine/year. The overall mortality rate for the windfarm, including the meteorological tower, was 27.58 birds/year. Most of the avian mortality occurred from August through October, and was composed of songbirds apparently killed while migrating at night. No raptor mortality was observed. About 84% of almost 400 hawks and vultures observed migrating through the windfarm area were at a height greater than the turbine rotors or below the windfarm in adjacent valleys. The variety of avian species captured by mist-netting was greater than that of the collision casualties, and the abundance patterns of individual species in the two samples were dissimilar. NEXRAD imagery of avian migration through the area showed relatively broad front-migration, with little concentration over the windfarm or other prominent landscape features. Avian mortality was poorly correlated with the intensity of migration as measured by NEXRAD imagery.

The adjusted bat mortality rate was 20.82 bats/turbine/year. No bat mortality was observed at the meteorological tower, and the overall windfarm mortality rate was 62.46 bats/year. About 70% of the bat mortality occurred from 1 August - 15 September. Six species of bats were among the casualties, and the most common casualties were red bats (61%) and eastern pipistrelles (24%). None of the six species are listed as endangered or threatened. Nights when bat mortality occurred tended to have lower wind speeds, less variation in wind speeds, and lower maximum temperatures than nights with no bat mortality. Bat activity levels were higher during nights when mortality occurred than with no mortality. Two species of bats were present in the area but not found among the casualties.

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1. INTRODUCTION

The commercial generation of electricity by wind has grown rapidly in the United States in recent years to a total installed capacity of approximately 6,374 megawatts (MW) at the end of 2003 (AWEA 2004). Although this represents a small fraction of the total generating capacity, it increased at an annual average rate of 28% between 1999 and 2003. Several factors have contributed to this recent increase, including improvements in wind turbine technology resulting in reduced production costs, consumer demand for non-polluting, renewable energy, and implementation of renewable portfolio standards in several states.

As with other sources of renewable energy, wind energy is generally considered to result in few environmental impacts. One area of concern since the late 1970s has been the death of birds from collisions with wind turbines. This first came to the attention of the public following reports of high raptor mortality (birds of prey including hawks, eagles, falcons, and owls) at Altamont Pass, California windfarms (Erickson et al. 2001). Over the last decade, avian mortality has been studied in detail at several windfarms in the West and Midwest, where over 90% of the wind power potential and most of the installed wind generating capacity are located (Elliott et al. 1987, AWEA 2004). From these studies, Erickson et al. (2001) calculated an average mortality rate of about 2.2 birds/turbine/year. Smallwood and Thelander (2004), using more recent data from Altamont Pass, calculated an average national mortality rate of 2.1 birds/MW/year; their estimate, based on rated energy output, controls for differences in turbine size. Both of these analyses showed considerable site-specific variation in both the mortality rate and the kinds of birds killed.

In recent years, interest in developing windfarms in the eastern United States has greatly increased, with over 300 MW of capacity installed and over twice that capacity proposed (excluding off-shore windfarms; AWEA 2004). Due of differences in terrain and vegetation, as well as in avian populations and migratory behavior, the applicability of the results of avian mortality studies at western and mid-western windfarms to the East is questionable. The same is true for bat mortality at windfarms, which has received less attention than avian mortality and has recently emerged as an area of concern (Erickson et al. 2002, Kerns and Kerlinger 2004, Williams 2004).

During the planning of its Buffalo Mountain windfarm, the first commercial windfarm in the southeastern United States, the Tennessee Valley Authority (TVA) recognized the limited available information useful in predicting avian mortality. The windfarm was proposed to be built in a heavily forested, mountainous area with high populations of nocturnally migrating songbirds and diurnally migrating raptors, particularly in the fall. TVA therefore committed to studying bird collision mortality for two years following construction of the windfarm. TVA later extended this commitment to three years and modified some study procedures to better measure bat mortality. Concurrent with the mortality studies, other related studies designed to develop better procedures for predicting bird and bat mortality were also carried out.

2. OBJECTIVES

Objectives of this study were to:

1. Estimate the number of bird and bat fatalities attributable to windfarm development.

2. Estimate the relative composition and abundance of the potentially vulnerable bird community through the use of acoustic monitoring, WSR-88D weather radar, visual observations, and mist-netting.

3. Evaluate the magnitude of the nocturnal bird migration at the windfarm in relation to other locations in East Tennessee.

4. Estimate the relative composition and abundance of the bat community through the use of acoustic monitoring and mist-netting.

3. OVERVIEW OF MORTALITY PREDICTION METHODS

Avian mortality at commercial wind energy facilities has been identified as an issue of concern since the 1970s, when the first large facilities were developed in California. Following the discovery of significant numbers of dead raptors at Altamont Pass windfarms, studies of avian responses to wind energy facilities were begun by regulatory agencies, local planning departments, and the wind energy industry (Anderson et al. 1999, Smallwood and Thelander 2004). Several workshops on the topic were held (e.g., PNAWPPM 1995) and an Avian Subcommittee of the National Wind Coordinating Committee was formed in 1994. The Subcommittee recognized the lack of standard protocols for studying wind energy/avian interactions, and in December 1999 issued a guidance document describing methods and metrics for assessing potential impacts of wind energy facilities on birds (Anderson et al. 1999).

The Anderson et al. (1999) guidance document describes techniques to evaluate potential windfarm sites prior to facility construction, monitor post-construction impacts, assess the significance of impacts, and reduce the risk to birds. Much of the guidance focuses on experimental design and the document recognizes that protocols for bird studies at windfarms are site- and species-specific.

The U.S. Fish and Wildlife Service has recently issued interim guidance on avoiding and minimizing wildlife impacts from wind energy projects (USFWS 2003). This guidance, intended to be used by Service staff providing technical assistance to the wind energy industry, focuses on pre-construction evaluation of windfarm sites and turbine siting, design, and operation issues. The recommended pre-construction evaluation is based on comparing a suite of site attributes such as physical characteristics, species present, and other ecological factors at proposed windfarm sites and nearby reference areas.

Commonly used techniques for predicting potential impacts to birds include literature review to identify the species likely to be present and to estimate the concentration of migrants in the area, as well as site surveys to determine the exact species present, their relative numbers, and site characteristics that may attract large numbers of birds (Anderson et al.

1999). More detailed site investigations include surveys of bird use of the area, often conducted by censuses of fixed areas in which bird numbers and activity, such as flight height and direction, are recorded (Gauthreaux 1996, Anderson et al. 1999, Erickson et al. 2002). While these techniques quantifying bird use have been relatively successful in describing observed impacts at several western and mid-western windfarms (e.g., Erickson et al. 2002, Smallwood and Thelander 2004), they do not assess potential impacts to nocturnal migrant birds, a concern in the eastern U.S. Techniques with potential for assessing potential impacts to nocturnal migrant birds include the use of NEXRAD (NEXt generation RADar, WSR 88-D) weather radar, marine surveillance radar, acoustic monitoring of nocturnal flight calls, and thermal imaging. These techniques vary in their applicability, range, spatial resolution, type of data collected, cost, and amount of data processing necessary to interpret results (Kelly 2000).

The techniques used in this study for birds were visual observations for migrating diurnal raptors; acoustic monitoring for nocturnal migrants; mist-netting for migrant songbirds; and NEXRAD radar for nocturnal migrants. The visual observations of migrating diurnal raptors were designed to determine their species composition, numbers, and flight behavior of raptors in the windfarm area. Similar “hawk watches” are conducted at numerous sites throughout North America to monitor raptor numbers and for recreational purposes (Zalles and Bildstein 2000). Acoustic bird monitoring records calls given during by nocturnal migrating birds and can quantify the number of birds passing over a site and often allow identification to species or groups of species (Evans and Mellinger 1999). Recent advances in automated processing have improved both the quantification and identification of recorded calls (Evans and Rosenberg 1999). The technique, however, has received limited use at windfarms (Evans 2000). Mist-netting can be an effective technique for determining the presence, species composition, and relative numbers of migrant songbirds present in an area (Ralph and Scott 1981). NEXRAD radar is an effective tool for monitoring broad-scale migration patterns including density, speed, and direction (Gauthreaux and Belser 1999, Larkin et al. 2002, Diehl et al. 2003, Gauthreaux et al. 2003).

Compared to birds, much less attention has been devoted to predicting bat mortality at windfarms. This is due, in part, to the low levels of bat mortality observed during many studies of bird mortality. The primary techniques used to assess bat activity at windfarms are acoustic monitoring and mist-netting (Erickson et al. 2002, Johnson et al. 2003a). Acoustic monitoring of bats in this study was designed to determine the species and relative numbers of bats in the windfarm area, determine seasonal and nightly patterns in bat activity, and to assess differences in bat activity in relation to habitat differences and height above ground. Mist-netting was used as a second method of identifying bats and determining their relative numbers. Acoustic detection and mist-netting are complimentary methods for determining species-specific bat activity (Kuenzi and Morrison 1998, O’Farrell and Gannon 1999). All of these study techniques were used concurrently with mortality monitoring of birds and bats in order to relate their findings with observed mortality.

4. CASE STUDY AREA

The field studies described here were carried out at the Tennessee Valley Authority’s Buffalo Mountain Windfarm located on Buffalo Mountain in Anderson County in eastern Tennessee (Figure 4-1). It is within the Cumberland Mountains on a north-northwest to south-southeast oriented ridgetop at an elevation of about 1,010 m. Approximate coordinates are 36° 7' 16" N, 84° 20' 19" W. The windfarm is constructed on a reclaimed coal surface mine.

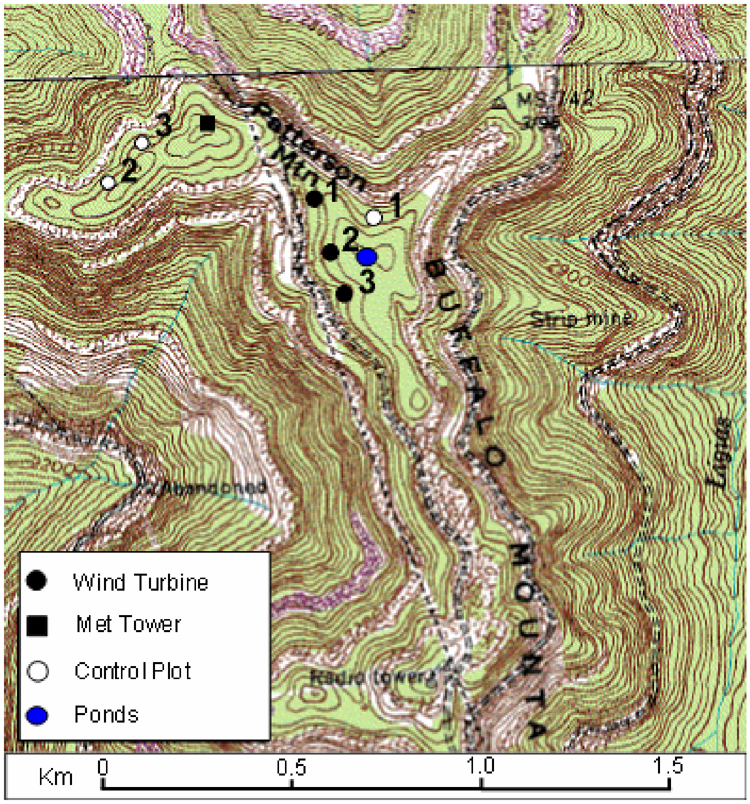


Figure 4-1. Configuration of Buffalo Mountain Windfarm, 2000-2003, showing locations of turbines, meteorological tower, control plots, and ponds.

The windfarm consisted of three Vestas V47 turbines, each rated at 660 kW, for a total nameplate generating capacity of 1.98 MW. The turbines are installed on 65 m tubular steel towers with a base diameter of 3.7 m. V47 turbines utilize an upwind, three-blade, pitch-regulated rotor 47 m in diameter. Total turbine height is approximately 89 m. The rotor turns at a constant speed of 28.5 rpm at all but very low wind speeds. The turbines begin generating power at a wind speed of 14.3 km/h and reach full power production at a wind speed of 54 km/h. At wind speeds exceeding 90 km/h, the turbines blades stop rotating.

Each turbine has aircraft warning lights mounted on top of the nacelle. These lights, Flash Technology model Flashtech 310, have dual white bulbs which flash day and night at a rate of 40 flashes per minute. Their intensity at night is 2,000 candelas.

A small pad-mounted transformer is located adjacent to the base of each turbine. Each turbine and transformer is surrounded by a 2.4 m high chain link fence approximately 15 m on a side. Underground electric cables connect the three turbines to a small substation adjacent to the southern-most turbine. The substation is enclosed by chain link fence and connected by an underground cable to a riser pole and 13-kV distribution line which runs to the south of the windfarm. The other major windfarm component is a 60 m meteorological tower located 350 m northwest of the northern-most turbine. The meteorological tower is supported by guy wires and does not have aircraft warning lights.

The windfarm was constructed during the summer and early fall of 2000. It was commissioned on October 12, 2000, becoming the first commercial-scale windfarm in the southeastern U.S. Additional information on the development and operation of the windfarm is available in two Wind Turbine Verification Program reports (EPRI et al. 2003a, 2003b).

The average annual wind speed 65 m above ground at the site from July 2001 through June 2003 was 6.67 m/s (14.92 mph) (EPRI et al. 2003b). The mean monthly wind speed is lowest during the months of June through September, when it ranges from 4.6 m/s (10.3 mph) to 5.7 m/s (12.8 mph). During the months of October through May, mean monthly wind speeds range from 7.1 m/s (15.9 mph) to 7.9 m/s (17.7 mph). On a diurnal basis, the highest winds occur between 2300 and 0500 hours. The prevailing wind blows consistently from the southwest and south-southwest with little seasonal variation (EPRI et al. 2003b).

5. METHODS

5.1. Fatality Searches

In order to estimate mortality of birds and bats, searches for fatalities were conducted at each of the turbines, the meteorological tower, and three nearby control plots (Figure 4-2). Searches were conducted within 50-m radius circular plots. Plot boundaries were marked with stakes and plastic flagging. The rapid growth of vegetation hindering search efforts, especially blackberry (*Rubus* spp.) and tree seedlings, was a continuous problem and the plots were periodically cleared using hand tools and by bush-hogging.

Searches usually began one to two hours after sunrise. The order in which plots were searched and the direction of the search transects varied between searches. Searches were conducted by at least two people, who systematically walked parallel transects 4 to 7 m apart back and forth across the plot. Plot searches typically lasted 20 to 40 minutes. The distance between transects and the time required to search a plot varied with terrain and density of vegetation.

Carcass searches were begun on 26 September, 2000, when turbine construction was concluding, and continued through 30 September, 2003. Searches were originally conducted twice a week during late August, September, October, April and May, once a week during November, March, June, July and early August, and twice a month during December, January, and February. In 2002, the search frequency was increased to twice a week during June, July, and early August to better measure bat mortality. Searches were conducted on a total of 215 days during the 3-year period.

The location (plot number, distance and bearing from plot center), species identity, and condition were recorded for all carcasses found. Where possible, carcasses were also aged and sexed. For birds, aging and sexing followed criteria in Pyle (1997). For bats, aging followed criteria in Anthony (1988) and sexing followed criteria in Racey (1988). Carcasses were labeled, bagged and frozen.

5.2. Fatality Search Biases

Because the ability of searchers in finding carcasses and the removal of carcasses by predators and scavengers both affect estimates of mortality, trials were conducted to measure both of these variables. Both variables were measured during the same trials, which were conducted on the search plots simultaneously with regular carcass searches.

These trials were conducted by placing tagged carcasses in randomly selected locations on the plots the evening before a regularly scheduled search. Carcasses were tossed into the air at the selected locations and left in the position in which they landed. Each carcass was marked with a small numbered plastic tag attached by a short piece of wire to the leg or forearm. The plastic tags were hidden from view by enclosing them in the fold of the wing or placing them under the carcass. Searchers conducted their regular searches the following day and were unaware of the presence of the tagged test carcasses until they found the first one. Immediately following the completion of the searches, the searchers received a list of the locations of the planted carcasses. The searchers then attempted to locate all planted carcasses not found during the regular search and determined whether the carcasses had been missed or scavenged. The searchers also attempted to relocate planted carcasses during subsequent searches.

Six trials were conducted. Two trials used only bird carcasses, one trial used only bat carcasses, and three trials used both bird and bat carcasses. All bird and bat carcasses had been frozen prior to their use in trials. A total of 89 bird carcasses were used; most of them were small to medium-sized songbirds, similar in size to common nocturnal migrants in the area. Forty-one of the carcasses were house sparrows and 21 were European starlings; the other songbird carcasses were a variety of road-killed and window-killed species. Two carcasses of larger birds, a ring-billed gull and an American crow, both road kills, were also used.

A total of 62 bat carcasses were used in the trials. These consisted of both intact bat carcasses retained from fatality searches and specimens originally acquired by the Centers for Disease Control for rabies analyses and later transferred to Dr. Gary McCracken at the University of Tennessee for genetic analyses unrelated to the windfarm study. About 60% of the bats were red bats; the remainder was comprised of five species which occurred in the windfarm area.

5.2.1. Estimation of Searcher Efficiency

Searcher efficiency, i.e., the proportion of bird and bat fatalities found by searchers, was expressed as the proportion of planted carcasses present that were found during the carcass search on the first morning of the trial. Searcher efficiency (e) was 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 meteorological 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.

5.2.2. Estimation of Carcass Removal

During the carcass search the morning after carcasses were planted and subsequent searches, searchers attempted to relocate the remaining planted carcasses. The length of time each individual carcass remained on the plot before being removed 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. The mean length of time a carcass remained on a plot ($\bar{t}$) was calculated using the following equation from Erickson et al. (2003a):

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

where *ti* 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. The use of a termination length of 20 days made 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 were pooled across trials since the number of trials was not large enough to detect 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).

5.2.3. *Estimation of Mortality Rates*

The estimated number of annual fatalities (*m*) per turbine and for the meteorological tower was calculated using the following formula from Johnson et al. (2003b):

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

where *N* is the total number of turbines (or meteorological towers), I is the interval between searches in days, *C* is the total number of carcasses found (adjusted to compensate for background mortality measured on control plots), k is the number of turbines (or meteorological towers) sampled, $\bar{t}$ is the mean length of time carcasses remained on site before being scavenged, and *e* is searcher efficiency. All three turbines and the single meteorological tower were searched on each visit and therefore *N/k* always equaled 1.

Mortality rates were calculated for each year starting 1 October and ending 30 September; the three years were averaged to yield adjusted mortality rates for turbines and for the meteorological tower. The overall adjusted mortality rate for the windfarm was determined by combining the turbine and meteorological tower results. Variances, standard errors, and 90% confidence intervals were calculated using standard formulas for a sample mean of the mortality estimates for the three years.

5.3. Measuring Avian Activity

5.3.1. *Acoustic Monitoring*

A weatherproof, self-contained acoustic monitoring station consisting of a microphone, an in-line amplifier, a laptop computer, and a 12-volt marine battery power supply was constructed following the design of Bill Evans of Old Bird, Inc. (www.oldbird.org, pers. comm.; Larkin et al. 2002). The microphone was oriented vertically to capture vocalizations of nocturnal migrants flying overhead. The computer, amplifier and power supply were housed separately from the microphone in a weatherproof container. In order to minimize electrical interference, the amplifier and computer were powered directly by the batteries. Audio signals detected by the microphone were processed by a transient detector computer program developed by the Cornell Laboratory of Ornithology and deployed with the assistance of Harold Mills. This software monitored the audio signal and recorded a small audio file whenever the power and amplitude of the signal reached a level consistent with nocturnal bird calls. These saved files could then be analyzed and identified as bird calls or interference. The acoustic monitoring station was located near the north edge of the C3 control plot, about 500 m from the nearest turbine and about 200 m from the meteorological tower. It was operated during spring and fall migration in 2001 and spring migration in 2002.

5.3.2. *Radar Monitoring*

NEXRAD images obtained from the Morristown, Tennessee National Weather Service office were processed by DeTect Inc. The images covered the period between sundown to sunrise during the spring (March 15–June 10) and fall (August 15–October 30) migrations in 2001 and 2002. Data in the images greater than 111 km (60 nautical miles) from the radar site was deleted because of the low accuracy in identifying bird targets at this distance. Weak signals, measured by negative dBZ values (a logarithmic unit of radar reflectivity) were removed. Areas of radar shadows caused by regional topography were also removed. Using proprietary software algorithms, DeTect Inc. removed weather-related and other non-bird targets from the images (Adam Kelly, DeTect Inc., pers. comm.). The remaining targets at various elevations in the NEXRAD images were combined into a signal dataset for each image (see Rinehart 1997 for a detailed discussion). The resulting datasets, about 3,700 images per season, were delivered in Arc/Info Geographic Information System (GIS) format.

The processed radar images were then analyzed by extracting the reflectivity values at Buffalo Mountain and at two additional sites: one site in the Ridge and Valley physiographic province, and one site in the Blue Ridge Mountains physiographic province. These additional sites were selected to be approximately the same distance from the radar site as Buffalo Mountain, and in locations with the same level of radar coverage as Buffalo Mountain. We analyzed each 15 minute interval from 1900–0300 for fall data and from 1800–0200 for spring data; these time periods captured the peak migration, which is typically between two hours after sunset and 0200 (Gauthreaux 2003). Average nightly dBZ values were computed for each site and then converted to discrete indices that ranged from 0-1 representing the lowest and highest dBZ values. Weekly averages were also computed to assess long-term trends and overall shifts in dBZ values. To determine if bird kills occurred on nights with high average dBZ values, the number of carcasses found and the corresponding reflectivity indices were graphed.

5.3.3. Visual Observations

Fixed point hawk watches were conducted at Buffalo Mountain on 8 days from 16 September through 27 October, 2001. This time period encompassed the peak of the fall hawk migration in East Tennessee, which occurs during the second half of September. Watches conducted in mid-September began at 0930 and concluded at 1530. Later watches were from 1130–1530. Two or more observers counted hawks and vultures from a point about 200 m east of the south-most turbine. Information recorded included species; number, including flock size where applicable; flight direction; and height relative to the turbine rotor-swept area.

Simultaneous hawk watches were conducted on 3 days in September from an extensive, flat, surface-mined area on Cross Mountain, about 19 km NNE of Buffalo Mountain, and on 1 day in September from a second site on Cross Mountain known as The Flag Pole about 13 km NE of Buffalo Mountain. The surface-mined site is at the edge of the Cumberland escarpment a short distance south of where the escarpment abruptly changes direction from NE-SW to NW-SE. The Flag Pole site is located about 6.5 km west of the point at which the escarpment changes direction from NW-SE back to NE-SW. Because of poor visibility from the 1077-m peak of The Flag Pole site, the hawk watches were conducted from two points on the upper flanks of the mountain. Based on the timing and numbers of hawks observed, there appeared to be little duplication in the observations from these two points.

5.3.4. Mist-Netting

Mist-netting was used to determine the composition and relative abundance of the population of small birds in the windfarm area during the autumn. Netting was conducted twice a week in 2001 and weekly in 2002, except during inclement weather. Seven to eight nets were operated along the narrow ridgetop of Patterson Mountain, about 1.5 km north of the windfarm site. Nets, each 6, 9 or 12 m long, 2.6 m high, and with 38 mm mesh, were spaced about 50 m apart perpendicular to the axis of the ridge. The nets were placed in cleared net lanes about 1 m wide in scrubby, post-mine reclamation vegetation consisting of blackberry, numerous forbs, autumn olive (*Eleagnus* spp.) and other shrubs, and scattered young trees. Nets were opened shortly before dawn and closed about 4 hours later. All birds were identified, aged and sexed using Pyle (1997), and banded with USFWS aluminum bands. Birds were also weighed and scored for the amount of subcutaneous fat deposits.

5.4. Measuring Bat Activity

5.4.1. Echolocation Detectors

Bat activity at Buffalo Mountain was monitored using Anabat® II bat detector systems (Titley Electronics, NSW, Australia; www.titley.com.au). Each Anabat detector was equipped with a zero crossings analysis interface module (ZCAIMs, Titley Electronics) attached to the microphone adapter on a laptop computer running Anabat software (version 6.2d). This system captured and digitally recorded bat vocalizations for later analysis. Each Anabat detector, ZCAIM, laptop computer and associated batteries was placed inside a plastic container. The Anabat microphone was attached to a plastic tube extending through a hole in the side of the container. See O'Farrell (1998) for a description of this system. These systems typically operated unattended for 2 to 4 days, depending on battery life.

One Anabat detector was operated from May 2001 through September 2003 about 52 m east of the middle turbine near the base of a brushy slope. This monitoring site, referred to below as the main pond site, was about 5 m from the edge of a small, shallow semi-permanent pond. The microphone for the Anabat detector at this site faced away from the turbines and towards the pond. Up to three additional Anabat detectors were operated during 2002 and 2003 at various locations including about 50 m northwest of the middle turbine, 600 m and 1000 m north and northwest of the turbines, and paired installations at the base and top of a 15-m tower 30 m south of Turbine 1, and at the tower base and on top of the nacelle of Turbine 2, 70 m above ground. Because of the potentially large inter-night variation in bat activity at a single site (Hayes 1997), only simultaneous recordings were used when comparing bat activity among sites.

Bat vocalizations recorded by Anabat detectors were transformed into an activity index. Files were first inspected using Analook software (Titley Electronics, version 4.8f); those containing at least one bat call were retained and other files were discarded. 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 series of calls emitted by an individual bat was defined as a "call sequence." The activity index (*AI*) was the percentage of one-minute increments (*m*) containing one or more bat files (*f*) for one complete night of monitoring (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/2003). The AI was used to standardize activity over lengths of nights that varied seasonally, as well as to reduce the probability that a bat was counted more than once for multiple echolocation calls emitted in close sequence (Miller 2001).

Call sequences recorded by the Anabat II systems were also analyzed to identify bats by species using the procedures of Britzke (2003; pers. comm.). Bat files were first filtered with the filter option in the Analook software to remove noise. Parameters for 10 call characteristics were then extracted with the Analook software and saved as text files. These files were then classified to species with the discriminant function model in Britzke (2003). This model included 12 of the 14 bat species whose ranges include Tennessee; the two species not in the model were the Seminole bat (*Lasiurus seminolus*), which is rare in Tennessee, and Rafinesque's big-eared bat (*Corynorhinus rafinesquii*).

5.4.2. Mist-Netting

Mist-netting was used as an independent means of determining the composition of the bat population in the windfarm area. Nets were placed over small ponds and across woods roads, both areas where bat activity was likely to be concentrated (Kunz and Kurta 1988). Special bat nets manufactured by Avinet®, Inc. were used; these nets were 12 m long, 2.6 m high, and had 38 mm mesh. Nets were either set up singly or paired end-to end. Nets were set up at the two ponds close to the turbines during most netting attempts; other locations used less frequently included a shallow pond in a dirt road near Control Plot 3 and a shallow pond in a dirt road on Patterson Ridge about 1 km northwest of the north-most wind turbine. Nets were opened at sunset and closed 3-4 hours later. Netting was conducted at irregular intervals during 2001, approximately weekly during 2002, and monthly during 2003. Netting was not conducted during inclement weather, including evenings when the temperature was forecast to be less than 10 ºC. Captured bats were identified to species, aging followed criteria in Anthony (1988), and sexing followed criteria in Racey (1988).

5.5. Statistical Analyses

Logistic regression, correlation, and T-tests were used to explore the relationships between mortality, activity, daily windfarm electrical generation, and several weather parameters for bats. For correlates with mortality, only those nights when the presence or absence of a fatality could be confidently assigned were used in these analyses. Because of the small number of avian fatalities for which a date could be assigned (19 casualties on 13 different dates), statistical analysis of these fatalities was not possible.

Windfarm electrical generation was recorded in KW-hours at 0800 daily (EDT), and thus one "day" covered the preceding 24 hours. Weather data was collected at 10-minute intervals from the meteorological tower on site by American Weather Service (AWS), under contract with TVA. 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 to describe a night's weather.

Potential explanatory variables available included year, month, 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 (225°), the predominant annual and autumn wind direction, 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 17 independent variables. Variables with a Spearman correlation coefficient $\geq$ 0.5 were considered correlated. To avoid multicollinearity, only one of a group of highly correlated variables was selected (i.e., 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 or the activity index for a night were used to select the independent variables to be included in the logistic regression.

The multivariate logistic regression was begun using a stepwise selection procedure with very high values (P = 0.99) and choosing the optimal number of predictor variables from the model with the lowest Akaike's Information Criterion (AIC; Burnham and Anderson 1998). A best subset selection procedure was then conducted on all possible models with ± two predictor variables 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). Using variables from this subset, analyses were then conducted 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).

6. RESULTS

6.1. Avian Fatalities

A total of 64 avian casualties of at least 26 species was found at the windfarm site. Forty-seven casualties of 19 species were found on the turbine plots, 14 casualties of 11 species were found on the meteorological tower plot, and 3 casualties of 3 species were found on a control plot (Appendix A). All but 2 of the casualties were fatalities. The exceptions were a red-eyed vireo on a turbine plot and a yellow-billed cuckoo on the control plot nearest to the turbines. The vireo initially appeared stunned and later flew away. The cuckoo had no obvious injuries but could not fly. It was not captured and its eventual fate is unknown.

In addition to the 3 casualties found on control plots, 3 other fatalities found on turbine and meteorological tower plots were classified as non-collision casualties. A yellow-billed cuckoo fatality found 5 October 2000 likely died prior to the completion of turbine construction and initiation of carcass searches and was not used in the mortality rate estimates. Similarly, two eastern towhees, both scavenged and one a fledgling, found on the meteorological tower plot were likely killed by predators and were not used in the mortality rate estimates. Two other fatalities found incidentally to regular carcass searches, a magnolia warbler found on a turbine plot on 14 September 2001 and a black-and-white warbler found on the meteorological tower plot on 4 August 2002, were also excluded from the mortality rate estimates.

The casualties represented three orders of birds: Gruiformes (cranes, rails and allies), Cuculiformes (cuckoos and allies), and Passeriformes (passerines/songbirds). None of the species are listed as endangered, threatened, or in need of management by the U.S. Fish and Wildlife Service or the State of Tennessee (TWRA 2004a, 2004b; USFWS 2004). The most frequently occurring species among the 60 combined turbine and meteorological tower casualties were the red-eyed vireo (12), golden-crowned kinglet (4), Tennessee warbler (4), bay-breasted warbler (4), and black-and-white warbler (4). About a fourth of the 42 passerine turbine casualties were red-eyed vireos and half of the remaining 16 species were represented by one individual. All of the meteorological tower fatalities were passerines and no species was represented by more than two individuals. Compared to the range in body size of the avian population in the windfarm area, the casualties were relatively small, ranging from about 5 g for the golden-crowned kinglet to about 50 g for the wood thrush and yellow-billed cuckoo and 100 g for the Virginia rail.

About 22% of the fatalities occurred during the late March – late May peak spring songbird migration period, and about 73% of the fatalities occurred during the mid-August – late October peak autumn songbird migration period (Figure 6-1). This pattern was relatively uniform across the three years of the study, although there was some annual variation within seasons (Figure 6-2).

Based on their breeding ranges, the date found, and/or physiological condition (i.e., presence of subcutaneous fat deposits), all but five of the birds were likely migrating at the time of their death. The exceptions were a cedar waxwing found 4 September 2002 on a turbine plot; a field sparrow found 15 May 2002 and eastern towhees found on 20 May 2002 and 11 July 2002, all on the meteorological tower plot; and a red-eyed vireo found 6 June 2002 on a control plot. All of these species nest in the windfarm area and, with the possible exception of the cedar waxwing, were likely nesting when they died.

The largest mortality events were in early October 2000 and late October 2002. Five dead birds were found on 10 October 2000; a strong, wet cold front passed through the region 3 days earlier, and the nights of 8 and 9 October were suitable for heavy migration with clear skies, unusually cold temperatures, and strong north winds. In the second event, eight dead birds were found on 31 October 2002. Most, and possibly all, of these birds were killed the previous night. The nights of 28 and 29 October were warm and rainy (NOAA 2002). Rain ceased the afternoon of 30 October and the night of 30 October was overcast with mild temperatures, conditions not typically associated with heavy migration.

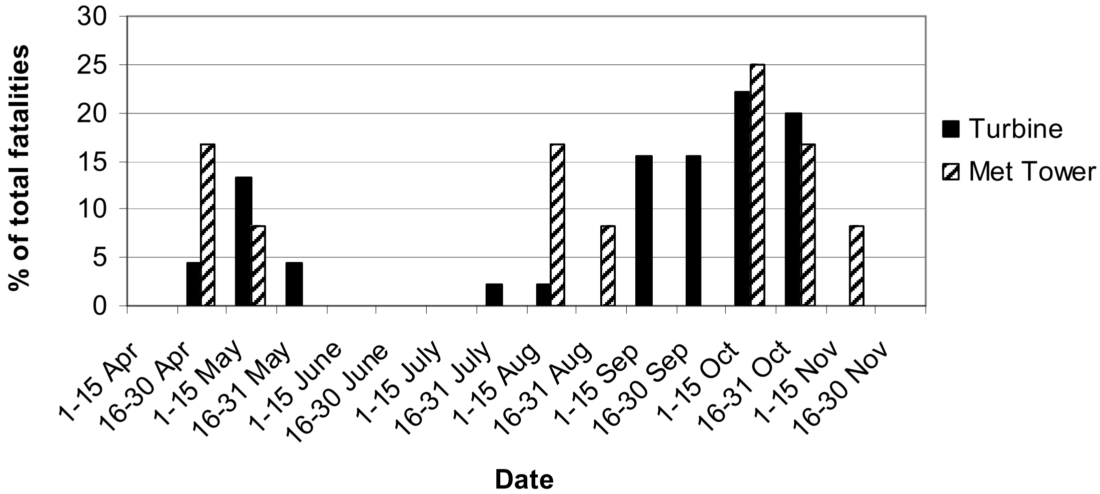


Figure 6-1. Seasonal distribution of bird fatalities at wind turbines and the meteorological tower, 2000-2003.

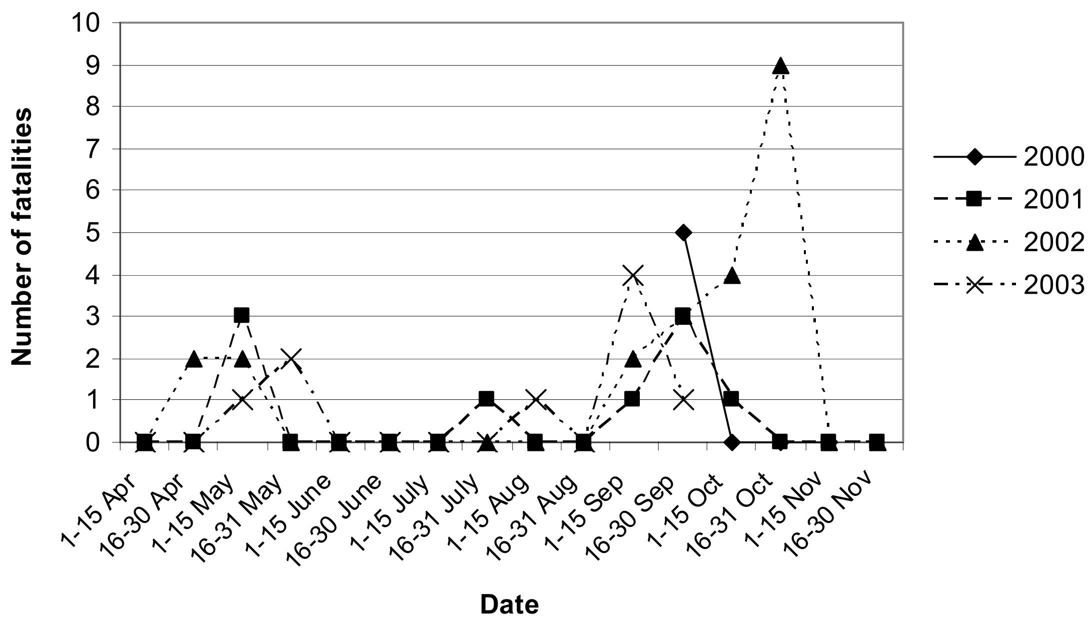


Figure 6-2. Annual and season distribution of bird fatalities at wind turbines, 2000-2003.

The median and mean distances that bird carcasses were found from the wind turbine towers were 25.4 and 24.4 m, respectively (range 0 - 50 m, SE = 2.1). Table 6-1 shows the carcass distribution in relation to distance and bearing from the turbine tower. Almost half of the birds were found south to southwest of the turbine towers, a likely consequence of winds from the north to northeast at the time of their deaths. Annual prevailing winds at the windfarm site are from the southwest.

6.2. Fatality Search Biases

Six fatality search bias trials were conducted using a total of 89 bird carcasses and 62 bat carcasses (Table 6-2). Two trials used only bird carcasses, one trial used only bat carcasses, and three trials used both bird and bat carcasses.

The proportion of carcasses present the morning after being placed and available to test searcher efficiency varied between trials from about 48% to 86% (Table 6-2). To a lesser extent, the proportion of bird and bat carcasses remaining overnight in the same trial also varied. This difference, however, was not significant (paired T-test, T = -1.69, P = 0.23), suggesting similar scavenger pressure on bird and bat carcasses during the first night of a trial. The average number of days a carcass remained in place varied between trials from 3.2 to 16.7 days, and averaged 6.3 days (N = 151, df = 5, 90% CI = 6.0, 6.7). Bat carcasses remained somewhat longer (7.0 days) than bird carcasses (5.8 days); this difference was not significant (T = 0.12, P = 0.91).

Table 6-1. Avian carcass distribution in relation to distance and bearing (in 22.5° sectors) from turbine tower.

	Distance from plot center					Total	
Bearing	0-10	10-20	20-30	30-40	40-50	N	%
N						0	0
NNE	1		1			2	4.3
NE				1	1	2	4.3
ENE		3	1	1	1	6	13.0
E		1	1	1		3	6.5
ESE	1			1		2	4.3
SE			1	1		2	4.3
SSE	1			1		2	4.3
S	1	1	2	4	1	9	19.6
SSW		2			1	3	6.5
SW	2	3	2	1	1	9	19.6
WSW	1					1	2.2
W						0	0
WNW	1			1		2	4.3
NW		2				2	4.3
NNW		1				1	2.2
Total	8	13	8	12	5	46	100
%	17.4	28.3	17.4	26.1	10.9	100	

Because of this lack of differences attributable to carcass type, results for bird and bat carcasses during individual trials were combined in determining both carcass survival and search efficiency rates. Similarly, because of the small number of trials, due in part to logistical constraints and concerns over repeatedly saturating the windfarm area with carcasses, and thus affecting the behavior of scavengers, no attempt was made to calculate adjustment rates by season or vegetation conditions and the results from the six trials were combined to derive overall estimates of 6.3 days for carcass survival and 37.0% for searcher efficiency. These estimates were used in determining the avian and bat fatality rates.

6.3. Estimation of Avian Mortality

Annual avian mortality rates, as well as overall average annual mortality rates, were calculated by adjusting the number of observed fatalities to compensate for search biases and background mortality determined on the control plots. Only those birds found dead on search plots during regularly scheduled searches were used in estimating mortality. Two dead birds were found on the three control plots during the three years, yielding a background mortality rate of 0.22 birds/plot/year.

Table 6-2. Results of fatality search bias trials to estimate searcher efficiency and carcass removal rate.

Trial	Date started	Grouping	Number placed	Number remaining after first night	Number found	Searcher efficiency (e)	Average no. of days carcass remained (t)
I	09/09/2001	bird	10	7 (70.0%)	1	14.3%	16.7
		bat	-	-	-	-	-
		combined	10	7 (70.0%)	1	14.3%	16.7
II	02/18/2002	bird	25	12 (48.0%)	5	41.7%	3.2
		bat	-	-	-	-	-
		combined	25	12 (48.0%)	5	41.7%	3.2
III	08/05/2002	bird	21	10 (47.6%)	7	70.0%	4.8
		bat	10	6 (60.0%)	5	83.3%	4.9
		combined	31	16 (51.6%)	12	75.0%	4.8
IV	09/20/2002	bird	-	-	-	-	-
		bat	22	11 (50.0%)	1	9.1%	4.7
		combined	22	11 (50.0%)	1	9.1%	4.7
V	05/12/2003	bird	15	13 (86.7%)	5	38.5%	5.6
		bat	14	12 (85.7%)	3	25.0%	6.2
		combined	29	25 (86.2)	8	32.0%	5.9
VI	07/212003	bird	18	13 (72.2%)	5	38.5%	7.3
		bat	16	13 (81.3%)	8	61.5%	13.9
		combined	34	26 (76.5)	13	50.0%	10.2
All trials		bird	89	55 (61.8%)	23	40.6%	5.8
		bat	62	42 (67.7%)	17	44.7%	7.0
		combined	151	97 (64.2%)	40	37.0%	6.3

The overall adjusted avian mortality rates for the turbines were 7.27 birds/turbine/year, for the meteorological tower, 5.77 birds/year, and for the whole windfarm, 27.58 birds/year (Table 6-3). The variances used in calculating confidence intervals for the mortality rates are from mortality estimates from three years, and do not account for the variances associated with the search bias corrections. Expressed in terms of generating capacity, the windfarm mortality rates were 11.02 birds/MW/year for the turbines and 13.93 birds/MW/year for the whole windfarm including the meteorological tower.

Table 6-3. Adjusted avian mortality rates for the Buffalo Mountain Windfarm, 2000-2003.

	Parameter estimate	Variance	SE	90% confidence interval
Searcher efficiency	0.37	0.10	0.13	(0.11, 0.63)
Scavenging removal time (days)	6.31	0.19	0.18	(5.95, 6.67)
Mortality rate - turbines (birds/ turbine / year)	7.28	12.96	2.08	(1.20, 13.34)
Mortality rate – met tower (birds/ met tower / year)	5.78	26.94	3.00	(-2.98, 14.52)
Total windfarm mortality rate (birds / year)	27.60	62.81	4.58	(14.23, 40.970

6.4. Avian Activity

6.4.1. Acoustic Monitoring

No useful information on nocturnal migrating birds was collected. Throughout the three seasons that acoustic monitoring was conducted, continuous problems were encountered with the recording equipment. The signal strength of the microphone was strong, and recorded test files were free of distortion. Although the apparatus made numerous recordings, no avian vocalizations could be discerned in the recordings. It was, however, very likely that birds were flying overhead within range of the microphone during the three migration periods sampled. The cause of the problems could not be determined and numerous attempts at troubleshooting, including consultations with Bill Evans (pers. comm.) were unsuccessful. In later discussions, Evans suggested that either the microphone element was not robust enough or, more likely, the electronics were not adequately grounded. The nature of the site (shallow reclaimed post-mining soils, low soil moisture) made grounding difficult, and a Faraday cage grounding structure may have been required.

6.4.2. Weather Radar Monitoring

Weather radar data from the Morristown, Tennessee NWS station were analyzed for the spring and fall seasons of 2001 and 2002. Figure 6-3 shows a sample processed radar image. The indexed radar data suggest that the intensity of nocturnal migration at Buffalo Mountain is similar to that at sites in the Ridge and Valley and in the Blue Ridge Mountains. The similar indexed DBZ values at these three sites during the spring and fall migration periods in 2001 and 2002 (Figure 6-4) indicate relatively uniform, broad-front movement of migrants across the landscape.

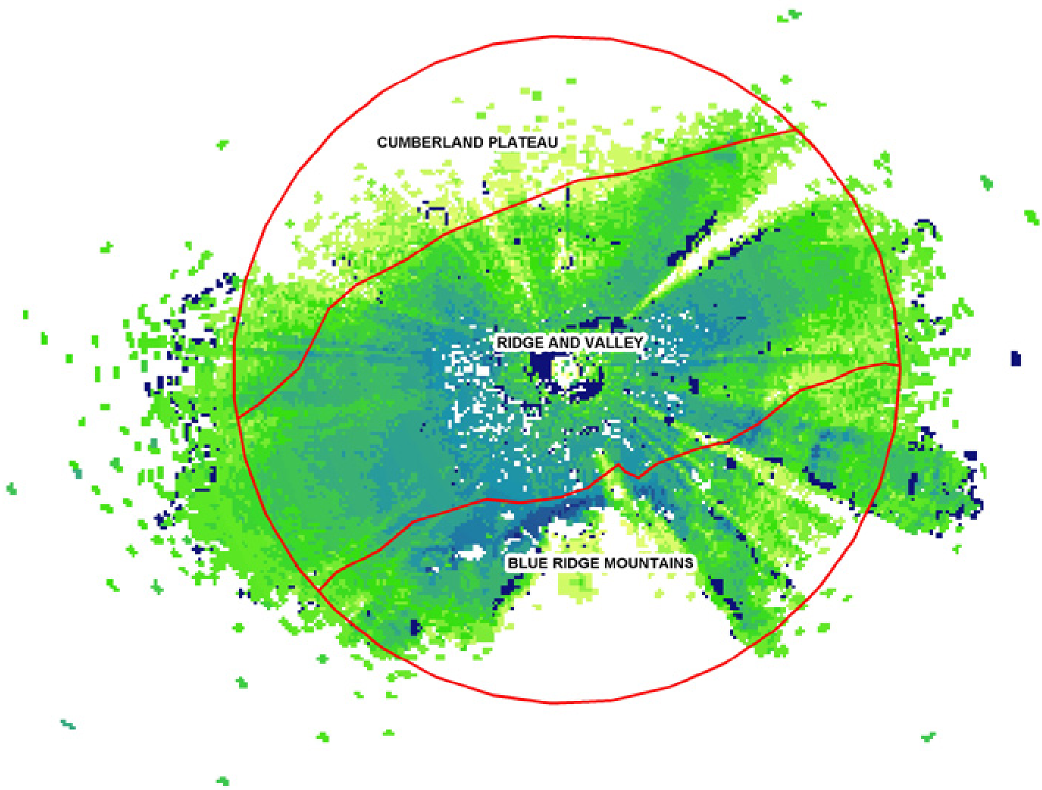
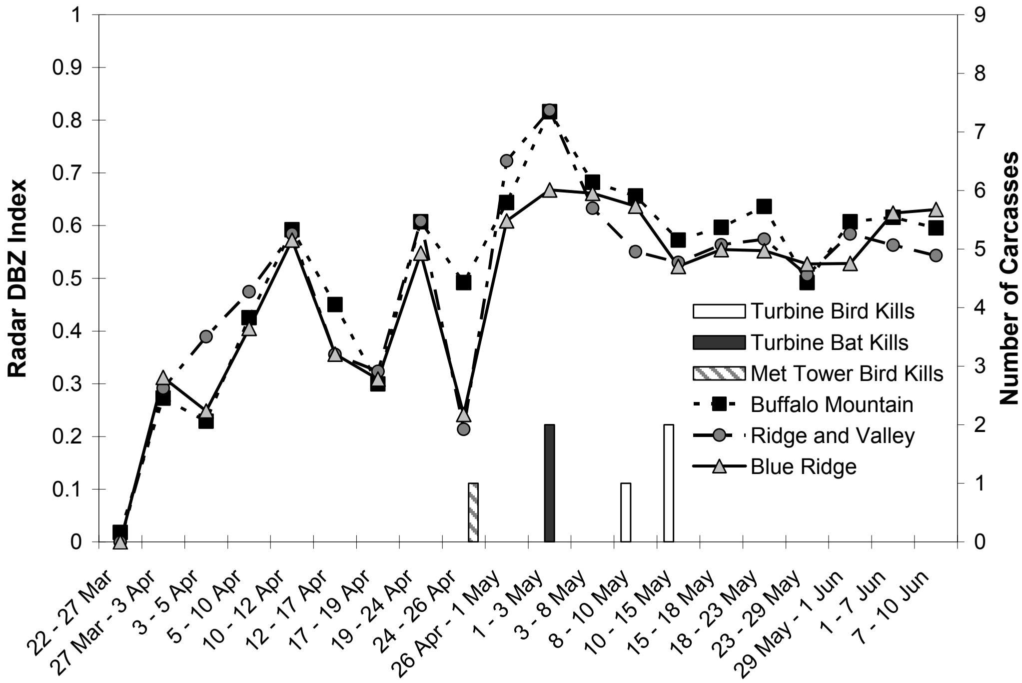


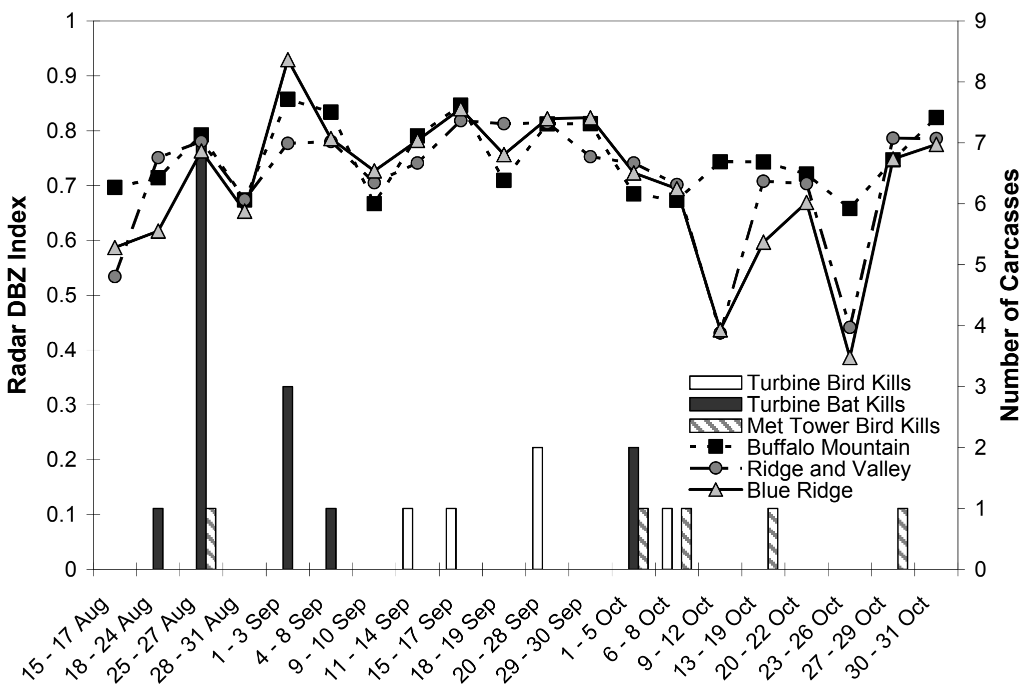
Figure 6-3. Sample processed radar image from the night of October 17, 2002. The blue-gray color represents the highest intensity of migration. Black represents ground clutter.

During each migration period, the intensity of migration generally increased early in the period and then fluctuated. Seasonal peaks were more pronounced during the spring than in fall, when the intensity of migration remained high for much of the season. Because these results are averaged over intervals of two to eight nights, they do not show some of the nightly differences in the intensity of migration due to weather conditions. Site-specific differences were most pronounced during October 2001 when the intensity of migration was somewhat greater at Buffalo Mountain than at the Ridge and Valley and Blue Ridge sites, and during much of the fall of 2002, when the intensity of migration at Buffalo Mountain was somewhat lower than at the other two sites. Overall, these results suggest that the potential risk to nocturnal migrants at Buffalo Mountain is similar at sites of similar elevation across the region.

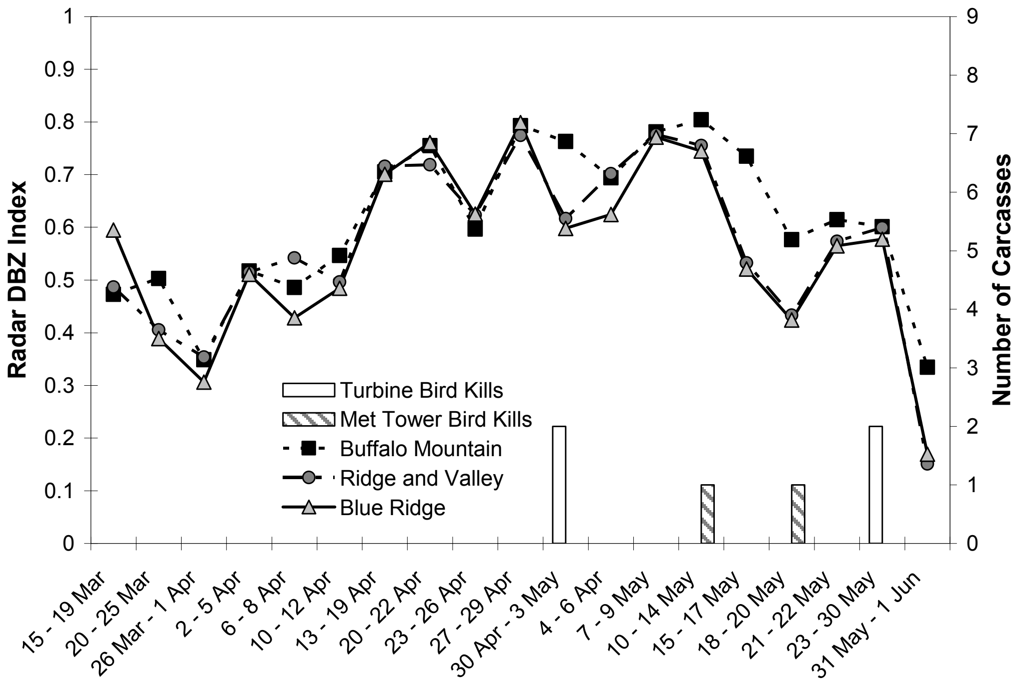
A) Spring 2001.



B) Fall 2001.



C) Spring 2002.



D) Fall 2002.

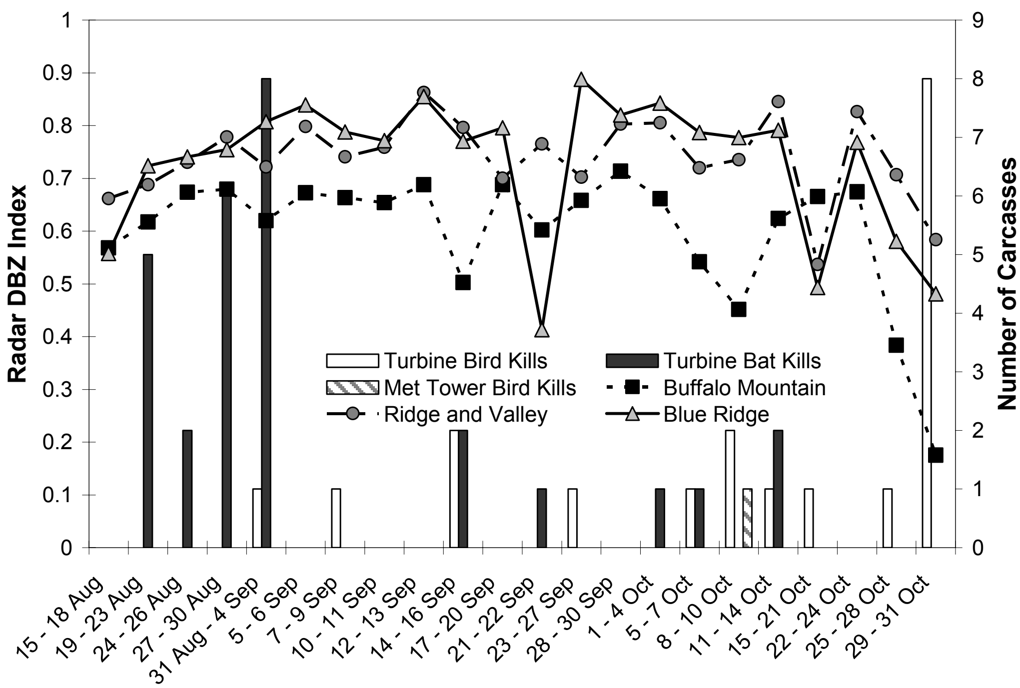


Figure 6-4. Averaged NEXRAD radar results at Buffalo Mountain, Ridge and Valley, and Blue Ridge sites and number of bird and bat fatalities at Buffalo Mountain. Horizontal axes show the time intervals between carcass searches. A) Spring 2001. B) Fall 2001. C) Spring 2002. D) Fall 2002.

6.4.3. Visual Observations

A total of 377 hawks and vultures were counted during 37.5 hours of observation during the autumn of 2001 (Table 6-4). The majority of these birds flew northeast to southwest, parallel to the Cumberland escarpment a few km east of the site. About 84% of the birds flew through the area at a height either above the maximum height of the turbine rotors or below the windfarm in adjacent valleys. A large proportion of the turkey vultures (27 of 37) and red-tailed hawks (9 of 17) flew at turbine rotor height; both of these species are present in the area much of the year. A large proportion of American kestrels (3 of 5 birds) and northern harriers (5 of 9 birds), as well as the only osprey and peregrine falcon, also flew through the area at turbine height. Very few of the hawks and vultures flying at turbine rotor height were in the immediate vicinity of the turbines and thus vulnerable to colliding with turbine rotors.

The magnitude of the fall raptor migration at the Buffalo Mountain windfarm was less than that observed during simultaneous observations at the two sites on Cross Mountain (Table 6-5). This difference may have been due, in part, to the fact that the windfarm site is further from the eastern Cumberland escarpment than the Cross Mountain sites. The escarpment forms a well-defined leading line that migrating hawks probably followed. The proportion of birds flying across each site at turbine rotor height varied greatly. At the Cross Mountain mine site, many birds approached the site from lower elevations in the broad valley to the east and gained elevation as they passed over the site. At the Cross Mountain Flag Pole site, many birds that passed east of the peak were below the peak.

Table 6-4. Results of hawk watches at the Buffalo Mountain Windfarm, autumn, 2001.

Date	Hours of observation	Turkey vulture	Broad-winged hawk	Red-shouldered hawk	Red-tailed hawk	Unidified *Buteo*	American kestrel	Peregrine falcon	Sharp-shinned hawk	Cooper's hawk	Unidified *Accipiter*	Northern harrier	Osprey	Unidified hawk	Daily Total
16 Sep	6.0	10	39	1	2		1							11	64
22 Sep	6.0	4	178		3	2	2		3			1			193
23 Sep	6.0	6	33		1	4		1		5	2	4	1	6	63
30 Sep	3.5	3	5			1					1	1		1	12
7 Oct	4.0	3			14				2	2					21
14 Oct	4.0	5													5
20 Oct	4.0	10					2			1		1			14
27 Oct	4.0	1			1				1			2			5
Total	37.5	42	255	1	21	7	3	1	6	8	3	9	1	18	377

Hawks and vultures were occasionally observed in the windfarm area during the spring and summer, and rarely during the winter. Although systematic observations were not conducted during these periods, very few hawks or vultures were observed in the immediate vicinity of the turbine blades.

Table 6-5. Results of simultaneous hawk watches at Buffalo Mountain Windfarm and two nearby sites, September 2001.

Date	Buffalo Mountain		Cross Mountain mine site		Cross Mountain Flag Pole site	
	Total	% at rotor height	Total	% at rotor height	Total	% at rotor height
16 Sep	64	15.6	112	91.9	712	4.1
22 Sep	193	2.6	211	28.9	-	-
23 Sep	63	28.6	423	8.3	-	-

6.4.4. Mist-Netting

A total of 404 birds of 40 species were captured during 26 days of mist-netting in September and October 2001 and 2002 (Table 6-6, Figure 6-5). The capture rate was highest during the second half of September. All but one of the birds captured were passerines; the exception was a sharp-shinned hawk (Appendix B). The most frequently captured species were, in descending order, the Tennessee warbler, magnolia warbler, ruby-crowned kinglet, hooded warbler, and white-throated sparrow.

Table 6-6. Avian mist-netting results at Buffalo Mountain.

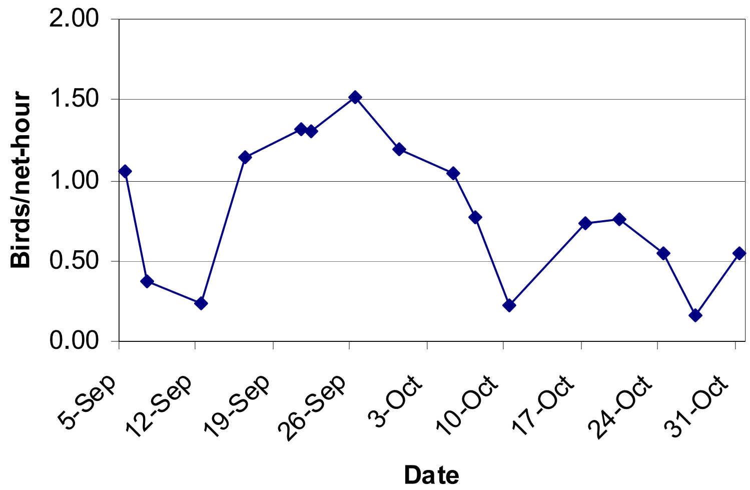
	Days	Birds captured	Species captured	Capture Rate (birds/net-hour)
2001	16	277	36	0.81
2002	10	127	23	0.69
Both Years	26	404	40	0.76

Most of the birds captured were migrants in the Buffalo Mountain area. Eight (22.5%) of the species captured are only present in the region as spring or fall migrants, 6 (15%) as winter residents and migrants, 15 (37.5%) as summer residents and migrants, and 10 (25%) are permanent residents. Populations of four of the permanent resident species are augmented during fall through spring by the presence of migrant and wintering individuals. Non-migratory permanent residents comprised 22% of all individuals captured. Of the 10 most frequently captured species, which made up 75% of all captures, only one, the northern cardinal, was a permanent resident. The fall and winter population of the cardinal is not augmented by the presence of migrants.

6.4.5. Avian Activity and Mortality

Because of the failure of the equipment for acoustic monitoring of the nocturnal migration of birds, it was not possible to correlate acoustic monitoring results with avian mortality.

A) 2001



B) 2002

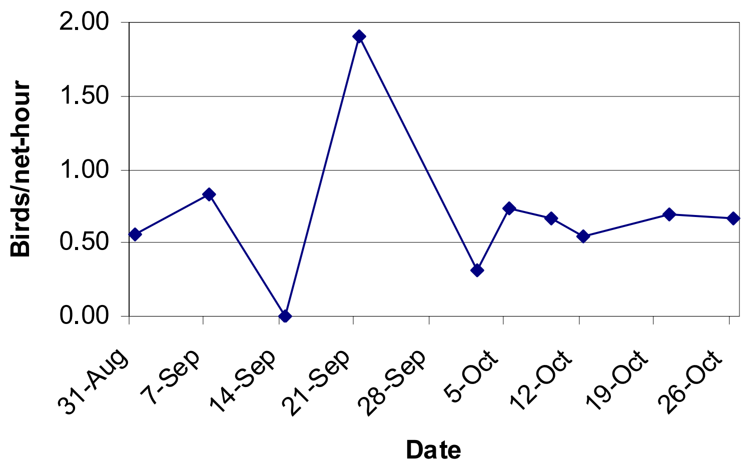


Figure 6-5. Avian mist-netting capture rate (birds/net-hour) at Buffalo Mountain during A) 2001 and B) 2002.

Avian mortality during a search interval was poorly correlated with the intensity of migration as measured by weather radar during the same time period (Figure 6-4). The lack of correlation with bird fatalities may be due, in part, to the overall small number of bird fatalities. The largest bird kill, eight between 29 and 31 October 2002, occurred during a time period when the number of migrants detected by radar was relatively low.

Hawks and vultures were most abundant in the windfarm area during the fall migration, which peaked in mid- to late September. At this time, about 16% of hawks and vultures flew through the area at turbine blade height, and were potentially at risk from collision with turbine blades. No evidence of hawk or vulture mortality was observed during the fall or during any other season.

Mist-netting results for birds showed relatively high capture rates during the second half of September. Avian mortality during this period, however, was not high relative to the rest of the fall (Figures 6-1, 6-2). The number of bird carcasses for which the date of death could be determined was too small to correlate daily mortality and daily mist-netting rates. Daily mist-netting rates were, however, poorly correlated (Spearman's r = 0.163) with the results of NEXRAD radar monitoring DBZ values from the preceding night.

6.5. Bat Fatalities

A total of 120 bat casualties were found at the windfarm site (Appendix C). Of this total, 115 were found on the turbine plots during scheduled searches and an additional four were observed incidentally to regular carcass searches. One bat, a scavenged red bat, was found on the control plot nearest the turbines. This bat was classified as a mist-netting mortality from nearby netting efforts the previous night. Two dead red bats were found near to but outside turbine plots and were likely turbine casualties. Only those bats found on the turbine plots during regular carcass searches were in mortality estimates. Five bats were still alive when found; because they all sustained injuries from which recovery was very unlikely (broken wings), they were euthanized on site and included in mortality estimates.

All bat casualties were identified to species (Table 6-7). Red bats made up the majority of casualties each year. Eastern pipistrelles and hoary bats were the next two most common casualties; their ranking, however, varied annually. Few individuals of the remaining three species were found and the Seminole bat is the northern-most record of this species in the state of Tennessee (Kennedy et al. 1984). None of the six bat species are listed as endangered, threatened, or in need of management by the U.S. Fish and Wildlife Service or the State of Tennessee (TWRA 2004a, 2004b; USFWS 2004).

Table 6-7. Species composition of bat casualties at Buffalo Mountain Windfarm.

	2000		2001		2002		2003		All years	
Species	No.	%	No.	%	No.	%	No.	%	No.	%
Red bat *(Lasiurus borealis)*	1	100	19	61.3	31	70.4	22	51.2	73	61.3
Eastern pipistrelle *(Pipistrelle subflavus)*			9	29.0	3	6.8	17	39.5	29	24.4
Hoary bat *(Lasiurus cinereus)*			1	3.2	9	20.4	2	4.7	12	10.1
Silver-haired bat *(Lasionycteris noctivagans)*			1	3.2			1	2.3	2	1.7
Big brown bat (*Eptisicus fuscus)*			1	3.2	1	2.3			2	1.7
Seminole bat *(Lasiurus seminolus)*							1	2.3	1	0.8
Total	1	100	31	100	44	100	43	100	119	100

Almost three-fourths of those bats for which sex could be determined were males and males outnumbered females for each of the three species with large sample sizes (Table 6-8). Adult bats made up almost two-thirds of the bats which could be aged and outnumbered juveniles of the three species with large sample sizes. Determination of sex and/or age was not possible for a large number of the casualties because of advanced decomposition or extensive scavenging. In addition, aging was often difficult in September and October when characteristics of the epiphyses were difficult to differentiate.

Table 6-8. Sex and age composition of bat casualties at Buffalo Mountain Windfarm.

	Red bat		Eastern pipistrelle		Hoary bat		Silver-haired bat		Big brown bat		Seminole bat		All Bats	
Sex	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Male	36	69.2	17	73.9	6	66.7	2	100	2	100	1	100	64	71.9
Female	16	30.8	6	26.1	3	33.3	0	0	0	0	0	0	25	28.1
Unknown	21	--	6	--	3	--	0	--	0	--	0	--	30	--
Age														
Adult	37	72.7	14	58.3	7	87.5	1	50.0	1	50.0	1	100	61	63.6
Juvenile	22	37.3	10	41.7	1	12.5	1	50.0	1	50.0	0	0	35	36.4
Unknown	13	--	5	--	4	--	0	--	0	--	0	--	22	--

The majority of the bat casualties (82.4%) occurred during the fall, defined based on bat biology as 16 July – 30 September (Table 6-9, Figure 6-6). About 70% of the fatalities occurred from 1 August – 15 September, and 96% occurred in an 88-day period centered on 22-23 August. The 6 fatalities during the winter (1 October – 15 April) were all in October. The mean numbers of fatalities per night during the four time periods were: spring, 0.01; summer, 0.07; fall, 0.42, and winter, 0.01.

Table 6-9. Seasonal distribution of bat fatalities, 2000-2003.

	2000		2001		2002		2003		All years	
	No.	%	No.	%	No.	%	No.	%	No.	%
1 Apr – 15 May	-	-	2	6.5	0	0	0	0	2	1.7
16 May – 15 Jul	-	-	7	22.6	4	9.1	2	4.7	13	10.9
16 Jul – 30 Sep	0	0	21	71.0	36	81.8	41	95.3	98	82.4
1 Oct – 31 Mar	1	100	1	0	4	9.1	-	-	6	5.0
Total	1	100	31	100	44	100	43	100	119	100

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. The median and mean distances that bat carcasses were found from the wind turbine towers were 20.2 and 19.9 ± 2.3 m (SE), respectively (Table 6-10). A regression analysis of the distribution of bat carcasses in relation to distance from the turbines, grouped into 5-m bands and corrected for area, best fit a non-linear curve ($y = 0.1233 – 0.1345 \ln(x)$, $r^2 = 0.84$, $P = 0.0002$) and predicted that no bat fatalities would be found beyond 40.6 m, although a few were found at greater distances. This result indicated that the 50-m radius search plots were of adequate size.

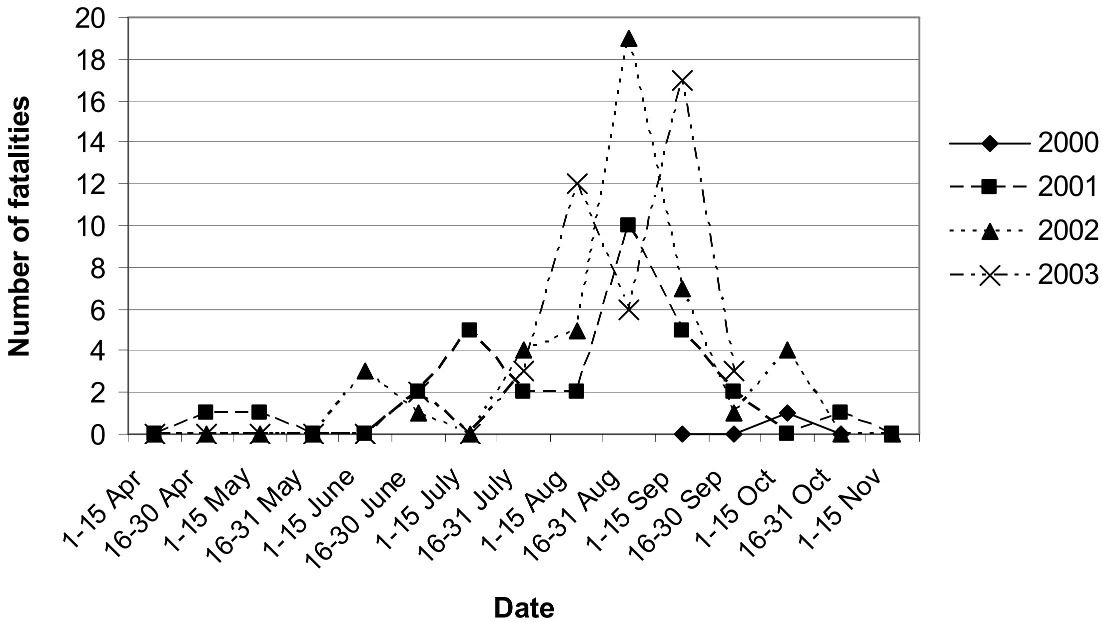


Figure 6-6. Annual and seasonal distribution of bat fatalities, 2000-2003.

Table 6-10. Bat carcass distribution in relation to distance and bearing (in 22.5° sectors) from turbine tower.

	Distance from plot center					Total	
Bearing	0-10	10-20	20-30	30-40	40-50	No.	%
N	2	1	2	2		7	6.0
NNE	3	1	4	3	1	12	10.3
NE	1		1	3		5	4.3
ENE	2	1	3	1	1	8	6.8
E	1	4	4	2		11	9.4
ESE	1	2	2			5	4.3
SE	1	2		2		5	4.3
SSE	1			2		3	2.6
S	1	1	3		1	6	5.1
SSW	1	3		1	1	6	5.1
SW	3	1	1			5	4.3
WSW	5		1	1		7	6.0
W	4	1	4			9	7.7
WNW	1	2	2			5	4.3
NW	5	1			1	7	6.0
NNW	6	3	5	1	1	16	13.7
Total, No.	38	23	32	18	6	117	100
%	32.5	19.7	27.4	15.4	5.1	100	

6.6. Estimation of Bat Mortality

Annual bat mortality rates, as well as the overall average annual mortality rate, were calculated by adjusting the number of observed fatalities to compensate for search biases. Because no bat fatalities were detected on control plots, no adjustment for background mortality was made. Only those bats found on search plots during regularly scheduled searches were used in estimating mortality.

Because there was no significant difference between bird and bat carcasses in either searcher efficiency or carcass survival time, the same correction factors used for estimating avian mortality were used to estimate bat mortality (see Section 6-2). The overall adjusted bat mortality rate was 20.82 bats/turbine/year (variance = 0.5833, SE = 0.4410, 90% CI = 19.53, 22.11). The variance used for this confidence interval is from mortality estimates from three years, and does not account for the variances associated with the search bias corrections. Bat mortality for the whole windfarm was 62.46 bats/year. Expressed in terms of generating capacity, the mortality rate was 31.54 bats/MW/year.

6.7. Bat Mortality, Windfarm Generation and Weather

Electricity generation at the windfarm was typically highest from October through May and lowest in June, July, August and September. Most of the bat mortality occurred during these months of low generation (Figure 6-7). On a nightly basis, the daily generation during the peak mortality periods of 1 August – 15 September 2002 and 2003 did not differ ($t = 0.13$, $P = 0.89$) between those nights when bat fatalities occurred ($n = 15$) and those nights when fatalities did not occur ($n = 37$).

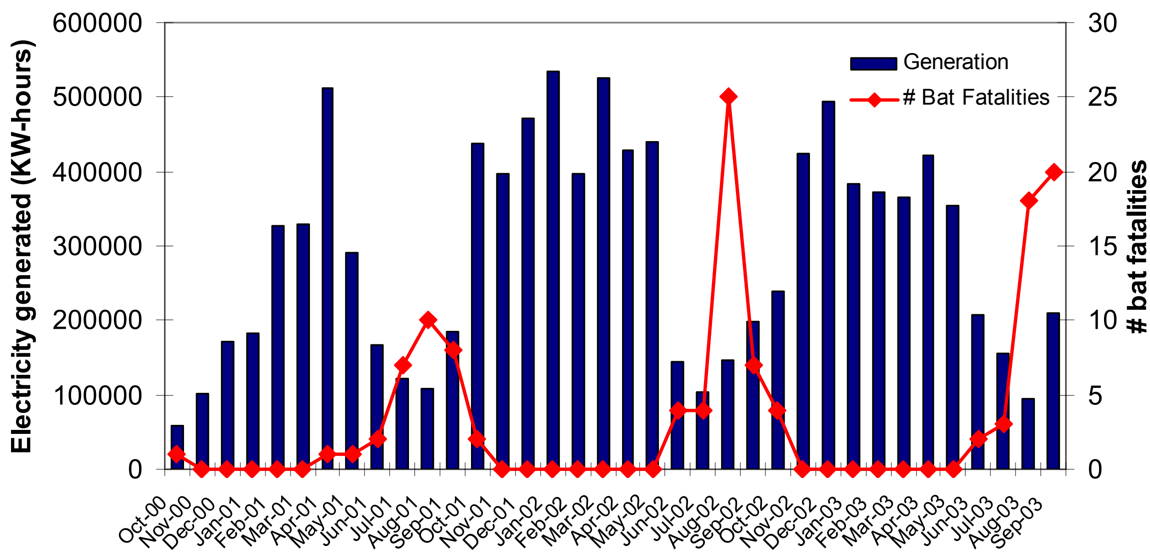


Figure 6-7. Monthly windfarm generation and number of bat fatalities found at the Buffalo Mountain Windfarm.

Nine models with 2 to 5 explanatory variables assessed the relationship between bat mortality and weather. Four of the 6 potential variables were consistently included in the 9 models: average nightly wind speed (-), wind speed difference (-), average nightly wind direction (+), and maximum temperature (-). The positive association with wind direction indicated that the greater the difference between wind direction and the predominant wind direction (from the SW), the greater the chance of a fatality event. The other three variables were negatively associated; thus the chance of a fatality event decreased as nightly wind speed, maximum temperature, and the difference between the average wind speeds during the first and second portions of the night increased. The differences in the average values of these weather variables between nights with and without fatalities, however, were small and may not be biologically significant.

Table 6-11. Average values of potential explanatory weather variables for nights with and without bat fatalities at Buffalo Mountain Windfarm, 1 August – 15 September 2002 and 2003.

	No. nights	Average nightly wind direction[a]	Average nightly wind speed (m/s)	Wind speed difference[b] (m/s)	Maximum nightly temperature (°C)
Nights with fatalities	15	1.1	4.4	0.7	21.1
Nights without fatalities	37	0.5	5.3	1.3	22.6

[a]Calculated as a value between 0 (SW wind) and 2 (NE wind) (Beers et al. 1966).
[b]Difference between average wind speeds during 1800-2400 hours and 2400-0600 hours.

6.8. Bat Activity

Of 611 possible recording nights between 1 April 2001 and 30 September 2003, 259 nights (42.4%) were monitored at the main pond site for the entire night (2001: n = 50, 2002: n = 126, 2003: n = 83; see Fiedler (2004) for a listing of nightly results). Bat activity levels were consistently greater during the late summer and early fall of each year (Figure 6-8). In 2002, bat activity increased in mid-July, peaked in mid-August, and declined into late September. In 2003, bat activity increased somewhat later in early August, peaked in mid-August, and declined earlier in September. The more limited 2001 data suggests a late July to mid-September peak.

The seasonal differences in bat activity were significant (F = 35.94, P = 0.03; Table 6-12). There was, however, no interaction between year and season (F = 0.01, P = 0.94). Multiple comparison tests (LSD) showed that the July – September AI was greater than the April – May AI, while the May – July AI did not differ from either the July – September AI or the April – May AI.

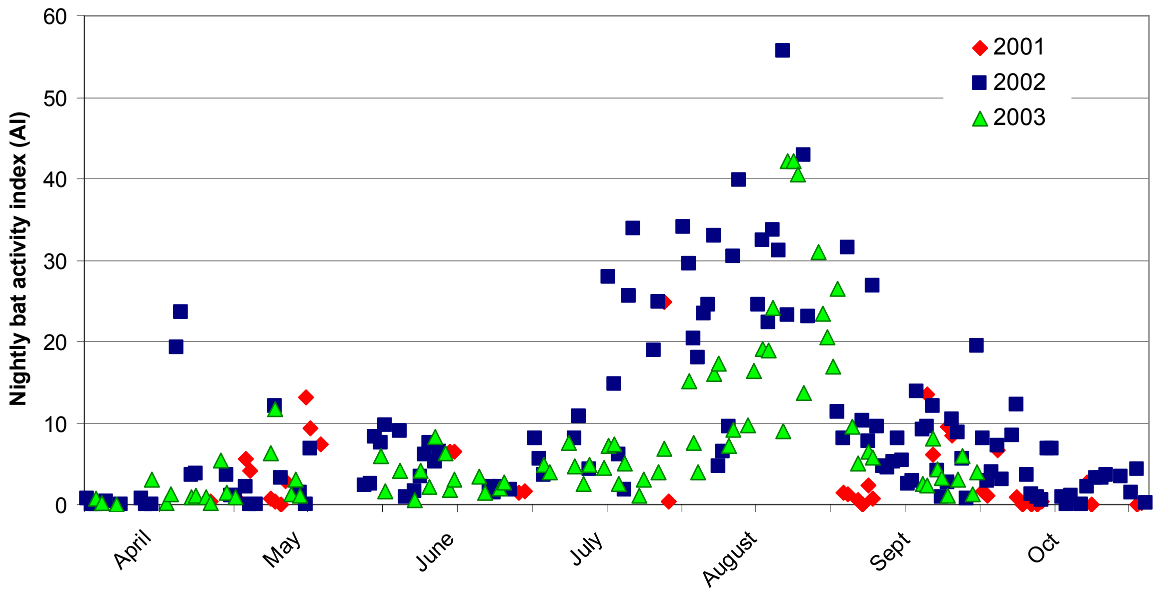


Figure 6-8. Annual bat activity, 2001-2003.

Table 6-12. Annual and seasonal bat activity index (AI) averages, 2002-2003.

	2002			2003			2002 and 2003		
	No. nights	Mean AI	SE	No. nights	Mean AI	SE	No. nights	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

Nightly bat activity at the main pond site consistently showed an initial increase at dusk and a decrease prior to dawn during all seasons (Figure 6-9). The greater bat activity during the July – September period relative to both the April – May and May – July seasonal periods is evident in these graphs. The 2002 data show a distinct bimodal pattern in activity with a reduction in activity during the middle of the night during the July – September time period, when it was most pronounced, and during May – July. During 2003, the bimodal pattern was not pronounced, and during the July – September time the increase in the evening and decrease in the morning were more gradual than in 2002.

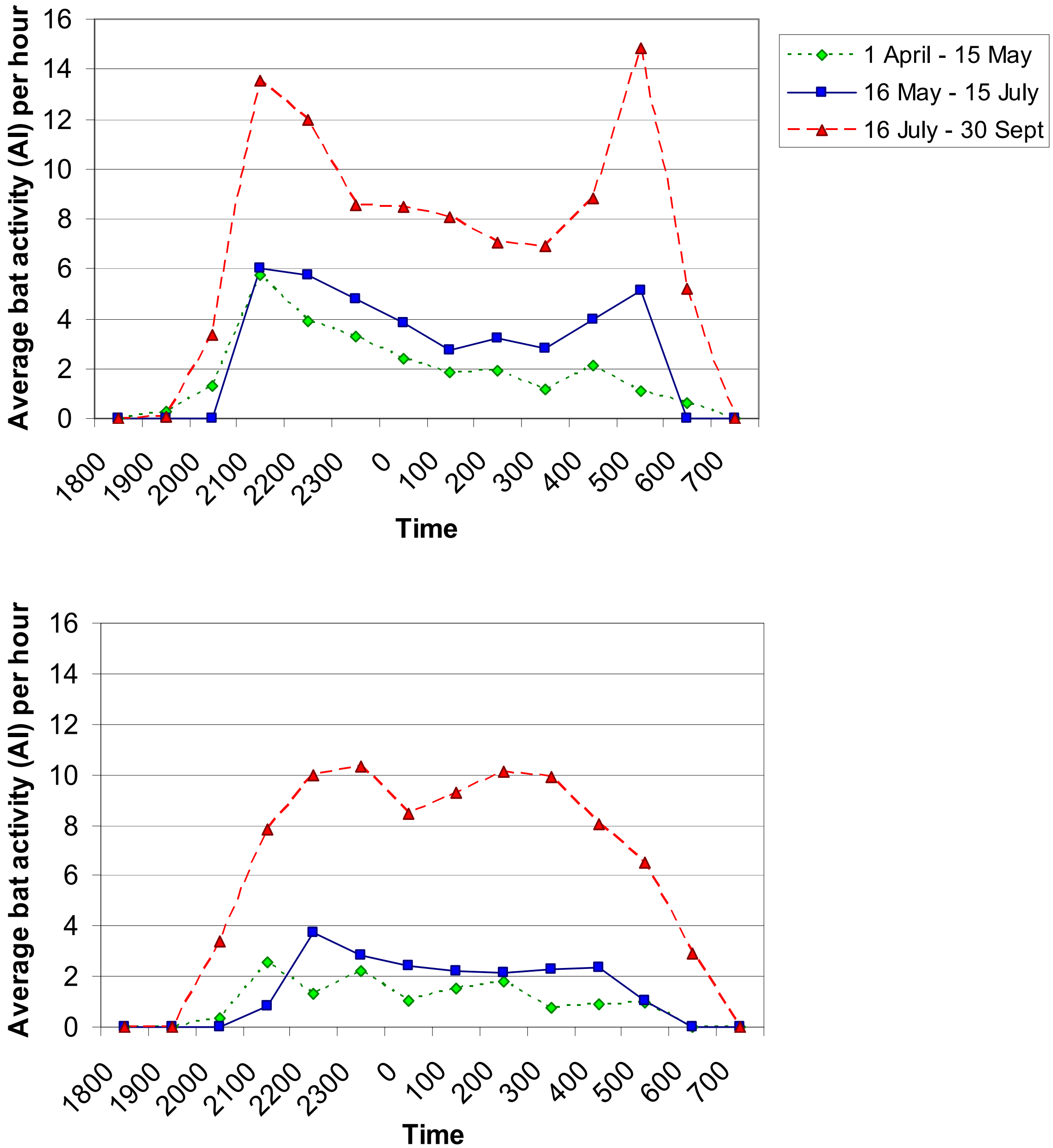


Figure 6-9. Mean hourly bat activity index (AI) by hour and seasonal period for 2002 (top) and 2003 (bottom).

Bat activity was not uniform across the windfarm area. Near the turbines, the mean AI at the main pond site, 9.74, was greater than the mean AI of 4.65 at the site 150 m from water at the base of Turbine 2 for 77 paired nights in 2002 and 2003 ($t = 11.21$, $P < 0.0001$). When the presence of water was held constant by monitoring near ponds, bat activity in the vicinity of the wind turbines differed from activity at two sites 600 m and 1000 m from the turbines. The mean AI at the first offsite area, 3.44, was less than the mean onsite AI of 9.26 during 37 nights in 2002 and 2003 ($t = 4.22$, $P = 0.0002$), while the mean AI of 22.90

at the second offsite area was greater than the mean onsite AI of 8.05 during 22 nights in 2002 ($t = -4.65$, $P = 0.0001$).

Bat activity was compared at ground-level and at heights of 15 m and 70 m above ground (Table 6-13). The AI recorded by paired bat detectors at ground-level and on a pole 15 m above ground did not differ ($t = 0.66$, $P = 0.26$). Significant differences were found in bat activity at the base of the Turbine 2 tower and on top of the Turbine 2 nacelle 70 m above ground for 28 nights during August – October 2002 ($t = 7.37$, $P < 0.001$) and for 9 nights during May – June 2003 ($t = 2.46$). In these two comparisons, bat activity was several times greater at ground level. The bat detectors on the turbine nacelle generally recorded more interference files than the ground-level detectors. However, the interference events were not consistent enough to attribute to turbine operations and most likely resulted from greater exposure to weather. Despite the significant differences in bat activity at the main pond site, the base of Turbine 2, and the Turbine 2 nacelle, the AIs for these three sites were strongly correlated (Table 6-14).

Table 6-13. Comparisons of bat activity index (AI) values at ground-level and at 15 and 70 m above ground at the Turbine 2 nacelle. The tested alternative hypotheses are that activity was greater at ground-level than above ground.

	No. paired nights	Mean AI at ground	Mean AI above ground	Mean difference	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 SEs are from original data.

Table 6-14. Spearman's rank correlations between bat activity indices (AIs) at the main pond site, at the base of Turbine 2, and on top of the Turbine 2 nacelle, 2002-2003. The tested null hypotheses are that Spearman's r = 0.

Sites	Nights	Spearman's r	P-value
Pond and Base of Turbine	77	0.8628	<0.0001
Pond and Top of Turbine	50	0.6689	<0.0001
Base of Turbine and Top of Turbine	38	0.5483	0.0004

6.8.1. Bat Activity and Mortality

Bat activity levels at the main pond site, expressed as AI, were compared between individual nights when bat fatalities occurred and nights without fatalities, and between search intervals when bat fatalities occurred and intervals without fatalities (Table 6-15). In the comparison of individual nights, bat activity levels were greater during nights with fatalities than nights without fatalities ($t = 2.54$, $P = 0.0067$). In the comparison of search intervals with and without bat fatalities, bat activity levels did not differ ($t = -1.05$, $P = 0.15$), although the low power ($\beta = 0.09$) of this test may have precluded a true difference from being found. Correlations between the average number of fatalities found and average bat activity levels during search intervals were positive for 2002 ($r = 0.49$, $n = 48$, $P = 0.0004$), 2003 ($r = 0.45$, $n = 38$, $P = 0.0050$), and both years combined ($r = 0.47$, $n = 86$, $P < 0.0001$).

Table 6-15. Comparisons of bat activity index (AI) values at the main pond site between individual nights and search intervals with and without bat mortality during 16 July – 30 September 2002 and 2003.

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

*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 satisfy normality assumptions; statistical parameters are based on the original data.

Bat activity levels at the main pond site were a poor predictor in the logistic regression model of bat fatality occurrence during search intervals (Wald X^2, $P = 0.22$, max rescaled $r^2 = 0.05$, correct classification = 66%). Bat activity levels were a better predictor in the model of bat fatality occurrence during individual nights (Wald X^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 to reach 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 levels at the top of Turbine 2 during 2002 did not differ significantly between nights with fatalities and nights without fatalities ($t=0.41$, $P = 0.69$, $N = 37$).

6.8.2. Bat Activity and Weather

During the July – September seasonal period, bat activity showed a positive relationship with average nightly temperature ($r = 0.60$, $n = 99$, $P < 0.0001$), a negative relationship with average nightly wind speed ($r = -0.31$, $n = 99$, $P = 0.0020$) and no relationship with percent moon face illuminated ($r = -0.02$, $n = 99$, $P = 0.8174$). The amount of daily electrical generation was positively correlated with wind speed (r = 0.62, n = 99, P < 0.0001) and negatively correlated with bat activity (r = -0.21, P = 0.04).

6.9. Bat Species Identification and Occurrence Patterns

Ten out of the 12 possible bat species were identified from the bat files recorded at Buffalo Mountain. When positive species identification of a call sequence was defined as greater than 50% of pulses within the call sequence identified to the same species, 2,081 (14.4%) of 14,462 bat files from the reference location were positively identified (2002 = 1,549; 2003 = 532). At a 75% confidence threshold 1,517 (10.5%) bat files 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 the 75% confidence threshold was used for the remaining species identification analyses. Three (little brown bat, *Myotis lucifugus*; Indiana bat, *Myotis sodalis*; and northern long-eared bat,) of the ten species identified acoustically never had more than one call in a single night and 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 (*Myotis grisescens*; E. Britzke, pers. comm.). Because the definition for presence requires more than one positively identified call in a single night, gray bats were also not considered present at Buffalo Mountain 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 6-16). Three additional species, silver-haired bat, hoary bat, and evening bat (*Nycticeius humeralis*) were considered present less than 10% of the monitored nights.

Table 6-16. Proportion of monitored nights bat species were acoustically identified two or more times.

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%

Four of the six bat species acoustically identified at Buffalo Mountain were present during the April – May period, five were present during May – July, and all six were present during July – September (Table 6-17). Silver-haired and hoary bats were most frequently recorded during April – May, and the remaining four species, the eastern pipistrelle, big brown, red, and evening bats, were most frequently recorded during the July – September period. The evening bat was present only during July – September.

Forty-nine bats of 5 species were captured in mist nets in the windfarm area during 14 nights in 2002 (n = 38 bats) and 4 nights in 2003 (n = 11 bats, Table 6-18). 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.

Table 6-17. Frequency of occurrence of bat species acoustically identified at Buffalo Mountain, expressed as the percentages of monitored nights that a species was identified. N = number of complete nights monitored.

	1 April – 15 May			16 May – 15 July			16 July – 30 Sep		
Species	2002 (n = 23)	2003 (n = 17)	2-year average (n = 40)	2002 (n = 26)	2003 (n = 24)	2-year average (n = 60)	2002 (n = 60)	2003 (n = 45)	2-year average (n = 105)
Eastern pipistrelle	4.3%	11.8%	8.1%	23.1%	25.0%	24.0%	60.3%	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%	8.5%	0%	4.2%
Hoary bat	8.7%	5.9%	7.3%	0%	4.2%	2.1%	1.7%	0%	0.8%

Table 6-18. Bat mist-netting captures at the turbine pond, Patterson Ridge, and Control Plot 3 sites.

	Pond			Patterson Ridge		Control Plot 3	All Locations
Species	2001 (n = 5 nights)	2002 (n = 10 nights)	2003 (n = 3 nights)	2002 (n = 2 nights)	2003 (n = 1 night)	2002 (n = 2 nights)	2001 - 2003 (n = 18 nights)
Red bat	11	26	8	1			46
Northern long-eared bat		2		1		1	4
Eastern pipistrelle		1		2	2		5
Big brown bat		1		2			3
Hoary bat	2	1	1				4
Unidentified*	2						
Total bats captured	15	31	9	6	2	1	64
Bats/net-hour	0.48	0.20	0.25	0.13	0.13	0.03	0.20

*Escaped from net prior to being identified.

The species composition of bats killed by colliding with turbines (Table 6-8), acoustically identified at the site (Table 6-16), and captured in mist nets (Table 6-18) varied. Table 6-19 compares the bat species composition of the different samples. Four species were identified by all techniques and three species were identified by only one technique. Because of the relatively limited sampling by mist-netting, comparisons of species compositions were only made between turbine fatalities and acoustic monitoring results. The species compositions in these samples was significantly different (Fisher's Exact Test, P = 0.008) during the peak July-September period. The proportion in turbine fatalities was less than the proportion acoustically identified for three species (eastern pipistrelle bat, big brown bat, and silver-haired bat) and greater for two species (red bat and hoary bat).

Table 6-19. Species composition of bats identified as turbine fatalities, captured in mist nets, and identified acoustically.

	% turbine fatalities				% mist-netted				% monitored nights a species was acoustically identified more than once		
	2001	2002	2003	All years	2001	2002	2003	All years	2002	2003	Mean, both years
Sample size	31[1]	44[1]	43[1]	87[1]	13[2]	38[2]	11[2]	49[2]	136[3]	86[3]	
Red bat	61.3	70.5	51.2	61.0	84.6	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	-	-	-	-	2.2	2.3	5.9
Hoary bat	3.2	20.5	4.7	10.2	15.4	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

[1]Number of fatalities.
[2]Number of bats captured.
[3]Number of nights monitored.
*The model used for acoustical identification did not include the Seminole bat.

7. DISCUSSION

7.1. Avian Mortality

The avian mortality rate at the Buffalo Mountain windfarm, 7.28 birds/turbine/year, is high relative to other U.S. windfarms. Erickson et al. (2002) reported a nationwide average of 2.19 birds/turbine/year, with a range of 0 to 2.83 at individual windfarms; more recent results from Altamont, California suggest a somewhat higher national average (Smallwood and Thelander 2004). Only two of the windfarms in the compilation by Erickson et al.

(2002) were in the eastern U.S. – one in Vermont and one in Pennsylvania. No mortality was observed during a year of monitoring at each of these windfarms. More recently, Kerlinger (2002) reported four turbine casualties during a 1-year study windfarm of a 7-turbine New York windfarm, and Kerns and Kerlinger (2004) reported a mortality rate of 4.04 birds/turbine/year during a 3-season study at the Mountaineer Wind Energy Center in West Virginia.

Nationwide, mortality of raptors (including vultures) varies greatly and makes up about a third of all bird mortality (Erickson et al. 2002, Smallwood and Thelander 2004). The great majority of reported raptor mortality has been at California windfarms with high resident raptor populations. The only eastern windfarms reporting raptor mortality have been in New York and West Virginia, where 2 and 3 dead raptors, respectively, were found (Kerlinger 2002, Kerns and Kerlinger 2004). Despite the presence of moderate numbers (i.e., up to about 200 birds/day) of migrating raptors during a short time period in the fall, no raptor mortality was observed at the Buffalo Mountain windfarm. These results suggest that the risk of raptor mortality at windfarms in the eastern U.S. is low.

Passerines (true songbirds) and songbird-like species (yellow-billed cuckoo) made up all but 1 (98%) of the 58 collision fatalities at Buffalo Mountain. This was a higher proportion that the average of 33% reported at western and mid-western windfarms by Erickson et al. (2002), although a few individual windfarms in the mid-west and northwest had proportions of passerines (85 – 91%) approaching that of Buffalo Mountain. About 93% of the fatalities at the Mountaineer windfarm in West Virginia were passerines (Kerns and Kerlinger 2004). The Mountaineer windfarm is much more similar to the Buffalo Mountain windfarm in terms of terrain and vegetation than are the other windfarms where mortality studies have been conducted and, as at Buffalo Mountain, nocturnal migrant songbirds dominated the bird casualties. Nocturnal migrants also comprised 71% of the songbird fatalities at the Buffalo Ridge, Minnesota, windfarm but comprised a low proportion of songbird fatalities at other mid-western and western windfarms (Johnson et al. 2002, Erickson et al. 2002). The high proportions of nocturnal migrant songbirds at Buffalo Mountain and Mountaineer are likely due, in part, to the higher populations and larger source areas of these species in the southeastern U.S.

Most of the avian mortality at Buffalo Mountain consisted of one or two individuals of a wide variety of species and thus likely had little to no effect on the populations of these species. This is likely also true for the most frequently killed species, the red-eyed vireo (11 fatalities), a widespread, abundant species both in Tennessee (Nicholson 1997) and in North America.

The species composition of the collision casualties during the fall differed somewhat from that of the fall mist-netting sample. Nocturnally migrating birds killed at tall structures are often assumed to represent a random sample of the birds flying through the area, while differences in habitat preferences and foraging behavior affect vulnerability to capture in mist-nets. In addition, the larger number of species present in the fall mist-netting sample (40 netted vs. 21 found as fall collision casualties) was expected given the larger mist-netting sample size (404 vs. 49 birds). The absence of red-eyed vireos in the mist-net sample was surprising, given its abundance during the fall in the region and its frequent use of the low vegetation sampled by mist nets. The only species that was among the most numerous species in both the mist-net sample and the collision casualties was the Tennessee warbler.

About 21% of the avian mortality at Buffalo Mountain occurred during the spring and 78% occurred during the fall. No more than two, and on one occasion three, birds were typically found during a carcass search. Exceptions were on 10 October 2000, when five dead birds were found and on 31 October 2002, when eight dead birds were found. The only other large avian mortality events reported at windfarms were 14 passerines killed at Buffalo Ridge, Minnesota, and 33 killed at Mountaineer, West Virginia. Both these events occurred during spring migration and the Mountaineer event was probably caused by the attraction of birds to sodium vapor lights during foggy conditions at the windfarm substation (Kern and Kerlinger 2004).

Because of the small number of avian casualties for which the date of death could be reliably determined, it was not possible to analyze correlations between avian mortality, daily electrical generation, and weather conditions. Mortality occurred under a variety of weather conditions. The 10 October 2000 mortality event, for example, occurred during clear, cold, windy conditions following passage of a strong cold front and the 31 October 2002 mortality event occurred during mild, rainy weather. The number of avian fatalities during the intervals between carcass searches was poorly correlated with migration intensity quantified from NEXRAD data. This relationship, however, may have been obscured by the relatively small number of fatalities, especially those for which the date of death could be determined. This prevented an analysis of the relationship between nightly fatality and nightly migration intensity.

All 3 turbines at Buffalo Mountain were lit with white strobe lights, as recommended by the U.S. Fish and Wildlife Service for communication towers (USFWS 2000), and thus comparison of mortality at turbines with and without lights was not possible. The avian mortality rate at the unlit 60-m tall, guyed meteorological tower was slightly less than that of the turbines. In a similar comparison at the Foot Creek Rim, Wyoming windfarm, Young et al. (2003) reported avian mortality rates of 1.8 birds/turbine/year and 7.5 birds/tower/year at 60-m tall, guyed meteorological towers.

Migration intensity at Buffalo Mountain (quantified using NEXRAD data) was similar to other sites in eastern Tennessee, suggesting that the Buffalo Mountain site does not pose a unique threat to migrants relative to other sites in the region. The Appalachians probably define a significant migratory corridor (Tankersley and Orvis 2003) with birds following wooded ridgelines on a northeast-southwest, spring-fall migration route. Any windfarm location in the Appalachians is likely to have some impact on nocturnally migrating birds. The Buffalo Mountain windfarm is located on a reclaimed surface mine surrounded by forest; it is unknown whether a more open, less forested site would experience less migration, and therefore less mortality. Local habitat conditions would likely only affect nocturnal migrants late in the night or early in the morning shortly after daylight as they settle to feed and rest (Hall and Bell 1981). Predicting a response to local habitat conditions is further complicated by the varied foraging techniques and habitat requirements of the numerous species of nocturnal migrants present in the eastern U.S. Most ridges in the eastern U.S. are forested, and given the correlation between wind speed and elevation, suitable alternative locations that are not surrounded by forest are absent in much of the east.

Acoustic monitoring has been used successfully in other monitoring studies, and the technology is proven (Larkin et al. 2002). We encountered significant technical problems that could not be resolved, and finally abandoned the technique after three field seasons. We suspect that the equipment was not properly grounded, although we did not record the static and interference we would expect. Recordings were clear and picked up insect sounds and wind, but never any nocturnal bird calls. Another possible cause is simply that the microphone we constructed was not suited to the task, although the design we used has been employed in other studies. We believe that this technique is still worth pursuing at other windfarm sites, particularly if a standard model is designed and produce by a third party.

7.2. Bat Mortality

The bat mortality rate at Buffalo Mountain, 20.8 bats/turbine/year, is one of the highest yet reported from a U.S. windfarm (Table 7-1). The only higher mortality rate reported is from the Mountaineer windfarm in West Virginia; this rate is based of preliminary results of a two-year monitoring program and limited searcher efficiency and carcass removal testing (Kerns and Kerlinger 2004). Bat collision mortality has been reported at other windfarms in California, Colorado, and Pennsylvania (Johnson *et al*. 2003a). Although mortality estimates are not available from these sites, the numbers of bat fatalities reported suggest the mortality rates were low.

Table 7-1. Bat mortality estimates at U.S. windfarms.

Windfarm	Years	Turbines	Bat fatalities/ turbine/year	Reference
Vansycle, OR	1999	28	0.74	Erickson et al. 2000
Northeastern WI	1999-2001	31	4.3	Howe et al. 2002 as cited by Johnson et al. 2003a
Foote Creek Rim, WY	1999-2002	105	1.3	Johnson et al. 2000b, Young et al. 2003, Gruver 2002
Buffalo Ridge, MN	2001-2002	281	2.16	Johnson et al. 2003a
Stateline, OR / WA	2001-2002	399	0.9	Erickson et al. 2003a
Klondike, OR	2002	16	1.2	Johnson et al. 2003b
Nine Canyon, WA	2002-2003	37	3.2	Erickson et al. 2003b
Mountaineer, WV	2003	33	47.5	Kerns and Kerlinger 2004
Buffalo Mountain, TN	2000-2003	3	20.8	this study

The species composition and seasonality of bat mortality at Buffalo Mountain has much in common with the other studies reported in Table 7-1. Bats of two genera, *Lasiurus* and *Lasionycteris* (the red, hoary, Seminole and silver-haired bats) made up 74% of the casualties at Buffalo Mountain, similar to the proportions at other windfarms (Johnson et al. 2003a, Erickson et al. 2003b, Kerns and Kerlinger 2004). The major difference is that hoary bats were the most frequent casualty at windfarms in the West and in Minnesota, and red bats were the most frequent casualty at windfarms in Wisconsin and West Virginia, as well as at Buffalo Mountain. Both of these species are widespread, solitary, foliage roosting species that migrate long distances (Barbour and Davis 1969, Cryan 2003). During the summer and early fall, the hoary bat is common in much of the West and Midwest and relatively uncommon in the Southeast (Shump and Shump 1982, Cryan 2003). The red bat is absent from most of the West, common in the Midwest during summer and early fall, and common throughout the year in the Southeast (Cryan 2003).

The silver-haired bat is also a migratory tree-roosting species, occurring solitarily or in small maternity colonies (Parsons et al. 1986); it has been more frequently reported among windfarm casualties in the West and Midwest than in the East. In the Southeast, it is most numerous during migration and winter (Cryan 2003). The Seminole bat is restricted to the Southeast and very rarely occurs in Tennessee (Kennedy et al. 1984). The single fatality at Buffalo Mountain, likely a vagrant, was the first reported mortality of this species at a windfarm.

The eastern pipistrelle made up about a quarter of the casualties at Buffalo Mountain. This species is often the most common bat in much of its range in eastern North America and inhabits caves, rock crevices, and, during the summer, trees (Barbour and Davis 1969). It may migrate short distances between summer roosts and winter hibernacula (Fujita and Kunz 1984). Eastern pipistrelles comprised about 2% of the casualties at Buffalo Ridge, Minnesota, and about 18% of the casualties at Mountaineer, West Virginia (Johnson et al. 2003a, Kerns and Kerlinger 2004). The sixth species killed at Buffalo Mountain, the big brown bat, has been an uncommon casualty at a few other windfarms (Johnson et al. 2003a, Kerns and Kerlinger 2004). This widespread species is sedentary or a short distance migrant that roosts in small colonies in buildings, hollow trees, and crevices in summer (Kurta and Baker 1990). It hibernates in buildings, mines and caves.

Small numbers of two other species of bats, the little brown bat and the northern long-eared bat, have been reported killed at other windfarms (Johnson et al. 2003a, Kerns and Kerlinger 2004). Neither of these species was found among the casualties at Buffalo Mountain. A few northern long-eared bats were mist-netted at the windfarm, and this species was common in nearby forests. It is considered non-migratory and forages in forested areas, often within the forest canopy (Fitch and Shump 1979); these factors likely reduced its vulnerability to collision mortality. The little brown bat was not observed in the windfarm area, although it does occur in the surrounding region. Evening bats were acoustically identified during a few nights at the windfarm but were not captured in mist nets or among the turbine casualties. This migratory species is not common in eastern Tennessee or eastern Kentucky, Ohio, and West Virginia (Barbour and Davis 1969, Watkins 1972), and thus few may have been present at Buffalo Mountain.

The concentration of bat mortality between 1 August and 15 September at Buffalo Mountain is very similar to that reported at other windfarms (Johnson et al. 2003a, Kerns and Kerlinger 2004). During this time period, bat movement increases as the rearing of pups is completed and migration, dispersal, swarming and/or breeding occur (Fenton and Thomas 1985). Bat activity at Buffalo Mountain, as measured by ground-level acoustic detectors, was also much greater during this August – mid September period than during the rest of the year. The increase in activity, however, began in mid-July, somewhat earlier than the late summer increase in mortality.

The relationship between bat mortality, bat activity, electrical generation and weather was complex. Nightly bat activity at the main pond site was greater during nights when fatalities occurred than during nights without fatalities. The number of bat fatalities found was also positively correlated with bat activity during the 3-4 day search intervals. Nightly bat activity at the top of Turbine 2 did not differ between nights with and without fatalities. Because of the strong correlation between bat activity at the main pond site and at the top of Turbine 2, we suspect that bat activity at turbine height does differ between nights with and without fatalities and that this difference was obscured by the small number of nights available for the comparison and the low level of bat activity measured at turbine height. Johnson et al. (2003a) failed to find a relationship between bat activity at ground level and the number of bat fatalities at turbines at the Buffalo Ridge, Minnesota windfarm. Similar analyses from other windfarms are not available.

The late summer-early fall peak in bat mortality coincided with the period of lowest winds and lowest electrical generation at Buffalo Mountain. The amount of daily generation was, obviously, strongly correlated with wind speed; daily generation was, however, a poor predictor of bat mortality during this period. Turbine blades rotate in light winds without generating electricity, and our data on turbine operation and the timing of bats collisions with turbines are not precise enough to determine whether bats collided with rotating or stationary turbine blades. We recommend this topic be further investigated by comparing bat mortality at normally operating turbines and turbines with blades locked into a stationary position.

During the late summer-early fall period, bat mortality was more likely during periods of lower average wind speeds, greater difference in wind speeds before and after midnight, wind directions other than southwest, and lower temperatures. Bat activity was greater at higher temperatures and lower average wind speeds. The relationship between bat activity and temperature has been widely reported (e.g., O'Farrell and Bradley 1970, Lacki 1984, Hayes 1997). Other reports also describe an inverse relationship between bat activity and wind speed (e. g., Adam et al. 1994).

Based primarily on the species composition and timing of bat fatalities at windfarms in the Midwest and Northwest, Erickson et al. (2002) and Johnson et al. (2003a) hypothesized that bat mortality at windfarms primarily involves migrating bats. Two of the three most frequently killed bats at Buffalo Mountain, the red bat and hoary bat, are migratory species and most mortality occurred during late summer and early fall. Red bats are also present in large numbers through the year, and were the species most frequently captured in mist nets from spring through fall, although very few were killed until mid-summer. In a study of radio-tagged red bats in eastern Kentucky, Hutchinson and Lacki (1999) noted late summer increases in both foraging areas and commuting distances between diurnal roosts and foraging areas. Male red bats were also more vagile and difficult to track in late summer.

The abundance of the red bat among the turbine kills and in mist-net captures was not reflected in the acoustic monitoring results, where the eastern pipistrelle and big brown bat were more frequently identified. This difference, however, is probably due to difficulties in identifying recorded red bat calls (Britzke 2003). Some authors have suggested, with little supporting evidence, that migrating bats may not echolocate during migration (Van Gelder 1956, Timm 1989). If this were commonly true, bat mortality should have been observed at the meteorological tower at Buffalo Mountain and at other windfarms. No bat mortality has been reported at windfarm meteorological towers and bat mortality is rare at communication towers and other tall, fixed structures (Erickson et al. 2002).

The eastern pipistrelle, which accounted for about a quarter of the bat mortality and was the species most frequently identified with acoustic detectors, is not considered a long-distance migrant. The reasons for its vulnerability to turbine collisions are not known. As with the red bat, a few eastern pipistrelles were killed during spring and early summer.

7.3. Recommendations

The avian mortality at the 3-turbine Buffalo Mountain windfarm was low enough that mitigation is not warranted. Whether the mortality rate at the windfarm expansion, consisting of 15 1.8-MW turbines, will be comparable to that of the existing turbines is unknown. The new turbines, with 80-m diameter blades and 15.5 rpm operating speed, are more typical of the 1.5 to 1.8-MW turbines currently being installed at U.S. onshore windfarms (AWEA 2004). Compared to one of the existing 660-KW turbines, the area swept by the rotor blades of the one of the new turbines is almost three times as large. The window of opportunity, i.e., the time period when a bird (or bat) can fly through the rotor plane at the tips of the blades while the rotor operated at normal speed (Smallwood and Thelander 2004), is much larger for the new turbines (1.29 seconds versus 0.70 seconds). Similarly, the area of the rotor plane swept per second by the turbine blades of one the new turbines is about half that of one of the existing turbines. These factors could decrease the risk of bird (and bat) collisions. The reduced risk to birds, however, could be partially offset by the turbines greater height and consequent increased risk of intersecting the flight paths of nocturnally migrating birds.

Few comparative controlled studies of different size turbines have been carried out at sites other than Altamont, California (Smallwood and Thelander 2004). Monitoring of bird and bat mortality at both the old and new turbines at Buffalo Mountain should be conducted for at least one year.

The 50-m radius plots used for carcass searches at Buffalo Mountain were of sufficient size to contain almost all of the bat fatalities. Because several bats, as well as birds, were found close to the outer edge of the plots, we recommend larger search plots be used for turbines taller than the 89-m tall turbines in our study.

Because of the potential for lights to attract birds migrating at night (Manville 2001), lighting on the turbines should be minimized to the maximum extent possible in accordance with Federal Aviation Administration regulations. If lights are not required on all the new turbines at Buffalo Mountain, mortality should be compared at lighted and non-lighted turbines. Lighting at other windfarm facilities, such as buildings and the electrical substation, should be minimized and, if feasible, equipped with motion detector switches. Minimization of lighting is especially important during inclement weather during spring and fall.

The bat mortality rate at the Buffalo Mountain windfarm is high enough to be of concern, and further investigation of factors associated with bat mortality is needed. Because most of the bat mortality at Buffalo Mountain occurs during a period of very low electrical generation, mortality at normally operating turbines and turbines with blades locked into a stationary position at night should be compared. If bat mortality is substantially lower at turbines with stationary blades, this may offer an inexpensive means of reducing bat mortality.

8. SUMMARY

We make the following conclusions based on the results of this study:

- The bird mortality rate was approximately 7.3 birds/turbine/year or 11.0 birds/MW of generating capacity/year. This rate is high relative to other U.S. windfarms.
- Bird mortality is dominated by nocturnal migrant songbirds of many species and there is little to no risk to raptors and vultures. Population-level impacts to individual species probably do not occur.
- The abundance of nocturnal migrant songbirds in the region, relative to other windfarms where bird mortality has been measured, is probably a major factor in the high bird mortality rate.
- Analyses of weather radar data showed a relatively uniform, broad-front movement of migrant birds and, from a geographic perspective, Buffalo Mountain does not appear to offer an unusually high risk to migrating birds. The intensity of migration, as measured by radar, was poorly correlated with avian mortality.
- The bat mortality rate was approximately 20.8 bats/turbine/year or 31.5 bats/MW of generating capacity/year. This rate is high relative to other U.S. windfarms.
- Most bat mortality occurred from early August through mid-September when bats were dispersing or migrating.
- Two of the three most frequently killed bats (red bat and hoary bat) are also among the species most commonly killed at other windfarms. Mortality of hoary bats was high relative to their abundance in the Buffalo Mountain area.
- During the early August – mid September period, daily electrical generation (over a 24-hour period) did not differ between nights when bat fatalities occurred and nights when fatalities did not occur. It is not known whether turbine blades were rotating when collisions occurred. Nights when fatalities occurred tended to have somewhat lower wind speeds, less variability in wind speed, lower maximum temperature, and a greater difference between wind direction and the predominant wind direction.
- Bat activity levels, as measured with Anabat detectors, were greater during nights with bat fatalities than nights without fatalities.
- Bat activity was lower in the immediate vicinity of the wind turbines than at a nearby pond, and lower on top of a turbine tower than at the base of the turbine. Bat activity levels at these three locations were strongly correlated.

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APPENDIX A – AVIAN CASUALTIES FOUND AT THE BUFFALO MOUNTAIN WINDFARM, OCTOBER 2000 – SEPTEMBER 2003.

Date	Species	Age[1]	Sex[2]	Plot	Distance from plot center, m	Bearing	Days since death
10/05/00	Yellow-billed Cuckoo*	U	U	T3	32.2	292	>10
10/10/00	Virginia Rail	AHY	U	T3	25.4	188	0.5-1.5
10/10/00	Hooded Warbler	HY	M	T2	32	188	0.5-1.5
10/10/00	Blackburnian Warbler	HY	F	T2	12	216	0.5-1.5
10/10/00	Golden-crowned Kinglet	AHY	M	T2	7.9	164	0.5
10/10/00	Palm Warbler	AHY	U	T1	24.6	190	0.5-1.5
04/26/01	Black-and-white Warbler	SY	F	M1	25.9	114	1.5-2.5
05/10/01	Acadian Flycatcher	ASY	U	T1	0	242	0.5-1.5
05/15/01	Yellow Warbler	ASY	M	T1	36.4	92	05.-1.5
05/15/01	Red-eyed Vireo	AHY	U	T1	29.1	62	2.5-3.5
07/20/01	Black-and-white Warbler	SY	M	T2	18.6	62	0.5-1.5
08/27/01	Black-throated Green Warbler	HY	M	M1	4.2	194	0.5-1.5
09/12/01	Magnolia Warbler**	U	U	T3	25	90	0.5-1.5
09/17/01	Yellow-billed Cuckoo	U	U	T1	13.4	314	U
09/28/01	Red-eyed Vireo	AHY	U	T3	16.4	206	0.5-2.5
09/28/01	Chestnut-sided Warbler	HY	M	T2	25.3	216	1.5-2.5
10/05/01	Bay-breasted Warbler	U	U	M1	4.5	112	0.5-1.5
10/08/01	Tennessee Warbler	U	U	T1	52.4	178	0.5-1.5
10/08/01	Chestnut-sided Warbler	HY	U	M1	58	112	0.5
10/19/01	Yellow-rumped Warbler	HY	M	M1	16.1	308	0.5
10/26/01	Lincoln's Sparrow	AHY	U	M1	14.2	48	0.5
11/14/01	Hermit Thrush	U	U	M1	16.5	180	0.5-1.5
04/29/02	White-throated Sparrow	SY	U	C1	47.1	286	0.5
04/29/02	Wood Thrush	ASY	U	T1	47.7	46	0.5-1.5
05/03/02	Hooded Warbler	ASY	F	T3	18.9	200	0.5-2.5
05/03/02	Yellow-rumped Warbler	U	U	T2	52	58	2.5-3.5
05/14/02	Field Sparrow	ASY	U	M1	10.7	279	0.5-1.5
05/20/02	Eastern Towhee*	FL	U	M1	29.5	334	U
06/06/02	Red-eyed Vireo	ASY	U	C1	39.5	302	2.5-3.5
07/11/02	Eastern Towhee*	U	U	M1	21.9	276	U
08/02/02	Hooded Warbler	HY	F	M1	7.1	142	1.5
08/04/02	Black-and-white Warbler**	U	M	M1	6	90	0.5
09/04/02	Cedar Waxwing	U	U	T3	38	220	U
09/09/02	Tennessee Warbler	HY	U	T1	6.7	20	0.5-2.5
09/16/02	Red-eyed Vireo	U	U	T2	18.3	185	1.5-2.5
09/16/02	Black-and-white Warbler	AHY	F	T3	33.2	145	1.5-2.5
09/27/02	Unid. Passerine	U	U	T2	6	284	U
10/07/02	Red-eyed Vireo	U	U	T1	11.8	315	0.5-2.5
10/10/02	Yellow-rumped Warbler	U	U	M1	14.3	116	0.5-2.5
10/10/02	Red-eyed Vireo	HY	U	T1	14.4	61	0.5-2.5
10/10/02	White-eyed Vireo	U	U	T1	40.6	200	0.5-2.5
10/14/02	Wood Thrush	U	U	T3	50.2	217	0.5-2.5
10/21/02	Golden-crowned Kinglet	U	F	T3	29.3	28	1.5-2.5
10/28/02	Golden-crowned Kinglet	U	F	T2	39	168	0.5-3.5
10/31/02	Golden-crowned Kinglet	U	F	T1	31.7	172	0.5-2.5
10/31/02	Tennessee Warbler	HY	U	T3	10.2	76	0.5
10/31/02	Tennessee Warbler	HY	U	T3	26.4	130	0.5
10/31/02	Chestnut-sided Warbler	U	U	T3	14	216	0.5
10/31/02	Unid. Passerine	U	U	T3	31.2	176	0.5
10/31/02	Bay-breasted Warbler	HY	M	T3	7.7	236	0.5
10/31/02	Bay-breasted Warbler	AHY	F	T3	2.9	232	0.5-1.5

Date	Species	Age[1]	Sex[2]	Plot	Distance from plot center, m	Bearing	Days since death
10/31/02	Bay-breasted Warbler	AHY	M	T3	15.1	224	0.5-1.5
04/25/03	Red-eyed Vireo	AHY	M	M1	30.6	310	1.5
05/08/03	Red-eyed Vireo	AHY	U	T3	30.2	56	0.5
05/08/03	Yellow-billed Cuckoo, live	AHY	U	C1	Live, walking	SW quadrant	0.5
05/19/03	Red-eyed Vireo	AHY	U	T2	11.3	343	0.5
05/27/03	Red-eyed Vireo	AHY	M	T1	6.4	172	0.5
08/05/03	Kentucky Warbler	HY	U	T3	13.2	85	0.5-1.5
09/02/03	Red-eyed Vireo, live, recovered	U	U	T1	46.2	43	0.5
09/02/03	Red-eyed Vireo	U	U	T2	9.3	104	2.5 - 3.5
09/05/03	Yellow-billed Cuckoo	U	U	T2	35.1	63	1.5
09/05/03	Blackburnian Warbler	HY	U	T1	35.2	186	0.5
09/12/03	Red-eyed Vireo	U	U	T2	28.4	235	2.5-3.5
09/16/03	American Redstart	AHY	F	T1	37.8	120	U

[1]Age Codes: AHY – After hatch year; ASY – After second year; FL – Fledgling; HY – Hatch year; SY – Second year; U – Unknown
[2]Sex Codes: F – Female; M – Male; U – Unknown
*Considered to be predator kill and not collision casualty
**Incidental find – not during regular mortality search

APPENDIX B – BIRDS CAPTURED DURING MIST-NETTING AT BUFFALO MOUNTAIN, AUGUST – OCTOBER 2001 AND 2002.

	Captures			Capture Dates	
Species	2001	2002	Total	2001	2002
Tennessee Warbler	58	18	76	5 Sep – 7 Oct	21 Sep – 12 Oct
Magnolia Warbler	49	17	66	5 Sep – 7 Oct	7 Sep – 12 Oct
Ruby-crowned Kinglet	36	24	60	30 Sep – 31 Oct	2 Oct – 26 Oct
Hooded Warbler	13	10	23	7 Sep – 26 Sep	31 Aug – 5 Oct
White-throated Sparrow	18	4	22	7 Oct – 31 Oct	9 Oct – 26 Oct
Ovenbird	8	6	14	5 Sep – 5 Oct	7 Sep – 9 Oct
Swainson's Thrush	8	6	14	16 Sep – 7 Oct	7 Sep – 12 Oct
Indigo Bunting	6	7	13	5 Sep – 5 Oct	31 Aug – 21 Sep
Northern Cardinal	6	4	10	16 Sep – 20 Oct	2 Oct – 5 Oct
Common Yellowthroat	6	2	8	16 Sep – 7 Oct	21 Sep – 5 Oct
Eastern Towhee	3	5	8	5 Oct – 24 Oct	21 Sep – 12 Oct
Carolina Chickadee	6	-	6	21 Sep – 24 Oct	-
Carolina Wren	4	2	6	26 Sep – 17 Oct	31 Aug – 2 Oct
Chestnut-sided Warbler	3	2	5	5 Sep – 12 Sep	21 Sep
Field Sparrow	1	4	5	31 Oct	21 Sep – 12 Oct
Black-throated Green Warbler	4	-	4	22 Sep – 26 Sep	-
Gray-cheeked Thrush	4	-	4	21 Sep – 10 Oct	-
Palm Warbler	4	-	4	21 Sep – 17 Oct	-
Black-and-white Warbler	3	-	3	5 Sep – 22 Sep	-
Golden-crowned Kinglet	1	2	3	7 Oct	20 Oct
Winter Wren	1	2	3	5 Oct	9 Oct – 26 Oct
American Goldfinch	2	-	2	20 Oct	-
Bay-breasted Warbler	2	-	2	22 Sep	-
Blackburnian Warbler	2	-	2	5 Sep – 26 Sep	-
Black-throated Blue Warbler	2	-	2	16 Sep – 7 Oct	-
Eastern Tufted Titmouse	2	-	2	31 Oct	
Gray Catbird	2	-	2	26 Sep	-
Song Sparrow	1	1	2	20 Oct	20 Oct
White-eyed Vireo	-	2	2	-	31 Aug – 21 Sep
Wood Thrush	1	1	2	22 Sep	2 Oct
Worm-eating Warbler	1	1	2	15 Sep	7 Sep
American Redstart	-	1	1	-	21 Sep
Blue-headed Vireo	1	-	1	26 Sep	-
Brown Thrasher	1	-	1	30 Sep	-
Dark-eyed Junco	1	-	1	31 Oct	-
Hermit Thrush	-	1	1	-	26 Oct
Nashville Warbler	1	-	1	30 Sep	-
Ruby-throated Hummingbird	1	-	1	22 Sep	-
Sharp-shinned Hawk	-	1	1	-	20 Oct
Yellow-bellied Flycatcher	1	-	1	16 Sep	-
Recaptures	11	4	15	-	-
Total Captures	277	131	408	-	-

APPENDIX C – BAT FATALITIES FOUND AT BUFFALO MOUNTAIN WINDFARM, 26 SEPTEMBER 2000 – 30 SEPTEMBER 2003.

Date Found	Turbine	Species	Age	Sex	Distance (m) from turbine	Bearing from turbine	Estimated date of death
2000							
01 Nov	3	Red bat	Adult	Male	27.2	174	30 Oct
2001							
03 May	2	Red bat	Adult	Male	35.4	16	30 Apr
03 May	2	Eastern pipistrelle	Adult	Male	25.4	14	01 May
06 Jul	2	Red bat	Adult	Unknown	50.0	348	na
06 Jul	2	Eastern pipistrelle	Adult	Female	12.0	334	03 Jul
06 Jul	2	Eastern pipistrelle	Juvenile	Male	2.0	324	na
13 Jul	2	Red bat	Adult	Unknown	6.0	332	10 Jul
13 Jul	2	Red bat	Juvenile	Male	7.2	306	12 Jul
13 Jul	2	Red bat	Adult	Male	2.3	224	10 Jul
13 Jul	3	Red bat	Adult	Unknown	7.0	10	10 Jul
25 Jul	3	Eastern pipistrelle	Adult	Female	13.1	82	23 Jul
25 Jul	1	Red bat	Adult	Male	6.7	342	22 Jul
08 Aug	1	Red bat	Juvenile	Male	28.0	340	06 Aug
08 Aug	2	Eastern pipistrelle	Adult	Female	22.0	41	05 Aug
24 Aug	3	Red bat	Adult	Female	33.0	42	23 Aug
27 Aug	3	Red bat	Adult	Unknown	17.1	57	25 Aug
27 Aug	3	Eastern pipistrelle	Adult	Male	17.1	90	24 Aug
27 Aug	3	Eastern pipistrelle	Adult	Male	17.1	202	24 Aug
27 Aug	2	Big brown bat	Adult	Male	6.8	277	24 Aug
27 Aug	2	Eastern pipistrelle	Adult	Male	16.2	302	24 Aug
27 Aug	1	Red bat	Adult	Female	15.1	300	24 Aug
27 Aug	1	Red bat	Adult	Unknown	6.4	235	25 Aug
03 Sep	3	Red bat	Adult	Female	2.4	230	02 Sep
03 Sep	2	Red bat	Adult	Female	12.3	25	02 Sep
03 Sep	2	Hoary bat	Adult	Female	6.5	162	02 Sep
05 Sep	2	Red bat	Adult	Female	8.3	324	03 Sep
09 Sep	1	Red bat	Unknown	Unknown	8.9	344	na
12 Sep	1	Eastern pipistrelle	Unknown	Unknown	4.9	288	na
14 Sep	2	Red bat	Adult	Unknown	6.4	10	na
01 Oct	3	Silver-haired bat	Juvenile	Male	31.8	353	30 Sep
05 Oct	1	Red bat	Adult	Male	6.3	20	na
02 Nov	2	Red bat	Adult	Male	22.6	328	30 Oct
2002							
03 Jun	1	Red bat	Juvenile	Male	17.2	135	2 Jun
06 Jun	3	Red bat	Juvenile	Unknown	20.5	92	4 Jun
*11 Jun	2	Big brown bat	Juvenile	Male	73.3	70	10 Jun
03 Jul	2	Red bat	Juvenile	Unknown	23.9	286	29 Jun
22 Jul	3	Eastern pipistrelle	Adult	Unknown	16.7	122	20 Jul
22 Jul	2	Hoary bat	Adult	Female	10.0	316	19 Jul
22 Jul	2	Hoary bat	Juvenile	Male	5.1	264	21 Jul
26 Jul	2	Red bat	Juvenile	Male	4.9	265	25 Jul
02 Aug	1	Eastern pipistrelle	Juvenile	Male	2.7	240	1 Aug
11 Aug	1	Hoary bat	Adult	Unknown	28.9	271	10 Aug
11 Aug	2	Red bat	Adult	Unknown	24.1	73	8 Aug
14 Aug	3	Red bat	Juvenile	Male	9.1	240	11 Aug
14 Aug	3	Hoary bat	Adult	Unknown	44.1	321	11 Aug
23 Aug	3	Red bat	Juvenile	Unknown	5.8	132	20 Aug

Date Found	Turbine	Species	Age	Sex	Distance (m) from turbine	Bearing from turbine	Estimated date of death
23 Aug	3	Red bat	Unknown	Female	20.5	43	22 Aug
23 Aug	3	Red bat	Unknown	Male	33.5	65	22 Aug
23 Aug	3	Red bat	Unknown	Unknown	56.8	94	na
23 Aug	3	Red bat	Unknown	Female	9.4	306	19 Aug
26 Aug	2	Red bat	Adult	Unknown	8.3	84	na
26 Aug	1	Red bat	Adult	Female	5.1	256	25 Aug
26 Aug	1	Red bat	Adult	Male	30.1	154	25 Aug
30 Aug	2	Red bat	Adult	Male	20.2	340	28 Aug
30 Aug	2	Hoary bat	Unknown	Male	16.5	325	29 Aug
30 Aug	2	Red bat	Adult	Female	32.6	22	27 Aug
30 Aug	2	Red bat	Adult	Male	30.1	2	26 Aug
30 Aug	1	Red bat	Unknown	Female	5.6	348	26 Aug
30 Aug	1	Eastern pipistrelle	Adult	Unknown	23.6	280	na
30 Aug	3	Hoary bat	Unknown	Male	47.7	65	29 Aug
*31 Aug	2	Red bat	Adult	Male	18.9	344	30 Aug
*31 Aug	2	Hoary bat	Unknown	Female	20.2	266	30 Aug
04 Sep	3	Red bat	Adult	Male	5.0	60	2 Sep
04 Sep	1	Red bat	Unknown	Male	35.4	158	3 Sep
04 Sep	1	Red bat	Unknown	Unknown	47.0	222	na
04 Sep	1	Hoary bat	Adult	Male	22.9	24	31 Aug
04 Sep	2	Red bat	Adult	Male	32.6	350	31 Aug
04 Sep	2	Red bat	Unknown	Unknown	6.0	338	2 Sep
09 Sep	2	Hoary bat	Unknown	Male	4.7	72	7 Sep
16 Sep	1	Red bat	Unknown	Male	30.1	130	15 Sep
16 Sep	3	Red bat	Juvenile	Male	29.4	115	14 Sep
22 Sep	2	Red bat	Unknown	Male	40.0	54	21 Sep
04 Oct	2	Red bat	Adult	Male	28.6	84	2 Oct
*5 Oct	3	Red bat	Juvenile	Male	~30m	~100	4 Oct
14 Oct	3	Red bat	Adult	Male	37.4	98	13 Oct
14 Oct	2	Red bat	Adult	Male	20.3	60	13 Oct
2003							
29 Jun	1	Eastern pipistrelle	Adult	Male	24.4	115	28 Jun
02 Jul	1	Hoary bat	Adult	Unknown	32.4	208	29 Jun
17 Jul	1	Red bat	Adult	Male	11.2	218	16 Jul
28 Jul	1	Red bat	Adult	Male	4.2	30	26 Jul
08 Aug	3	Red bat	Adult	Unknown	40.0	80	na
08 Aug	2	Red bat	Juvenile	Male	6.8	182	06 Aug
08 Aug	2	Eastern pipistrelle	Juvenile	Female	27.8	238	06 Aug
08 Aug	1	Eastern pipistrelle	Adult	Female	7.5	210	06 Aug
08 Aug	1	Eastern pipistrelle	Juvenile	Male	2.4	331	06 Aug
12 Aug	3	Red bat	Juvenile	Unknown	13.4	197	09 Aug
12 Aug	3	Eastern pipistrelle	Juvenile	Male	18.4	261	10 Aug
12 Aug	3	Red bat	Juvenile	Female	25.5	334	10 Aug
12 Aug	1	Eastern pipistrelle	Juvenile	Female	4.1	276	10 Aug
12 Aug	1	Eastern pipistrelle	Juvenile	Male	21.2	291	10 Aug
12 Aug	1	Red bat	Juvenile	Unknown	23.7	258	08 Aug
15 Aug	1	Eastern pipistrelle	Juvenile	Male	19.0	6	14 Aug
18 Aug	3	Red bat	Juvenile	Unknown	22.2	223	17 Aug
21 Aug	3	Red bat	Juvenile	Unknown	2.6	251	18 Aug
21 Aug	2	Red bat	Juvenile	Male	34.1	346	20 Aug
21 Aug	1	Eastern pipistrelle	Unknown	Unknown	31.2	140	na

Date Found	Turbine	Species	Age	Sex	Distance (m) from turbine	Bearing from turbine	Estimated date of death
02 Sep	1	Red bat	Adult	Male	21.4	69	29 Aug
02 Sep	2	Eastern pipistrelle	Unknown	Male	18.0	87	29 Aug
02 Sep	2	Red bat	Juvenile	Unknown	43.1	20	29 Aug
05 Sep	3	Red bat	Juvenile	Female	27.9	181	04 Sep
05 Sep	1	Red bat	Juvenile	Male	22.1	188	04 Sep
09 Sep	3	Eastern pipistrelle	Adult	Male	8.8	30	07 Sep
09 Sep	1	Eastern pipistrelle	Adult	Male	25.9	342	07 Sep
09 Sep	1	Red bat	Adult	Male	24.3	22	05 Sep
09 Sep	1	Red bat	Adult	Male	24.0	270	08 Sep
09 Sep	1	Silver-haired bat	Adult	Male	36.7	12	08 Sep
09 Sep	1	Eastern pipistrelle	Juvenile	Male	28.5	5	08 Sep
09 Sep	1	Red bat	Juvenile	Female	16.5	88	07 Sep
09 Sep	1	Eastern pipistrelle	Juvenile	Male	22.9	342	07 Sep
12 Sep	3	Eastern pipistrelle	Unknown	Unknown	19.5	210	na
12 Sep	3	Eastern pipistrelle	Juvenile	Male	31.8	258	11 Sep
16 Sep	3	Red bat	Adult?	Female	16.1	123	14 Sep
16 Sep	3	Seminole bat	Adult	Male	18.5	126	15 Sep
16 Sep	3	Eastern pipistrelle	Adult	Male	17.3	170	14 Sep
16 Sep	3	Red bat	Juvenile	Female	37.8	51	14 Sep
16 Sep	1	Red bat	Adult	Female	34.5	120	15 Sep
23 Sep	2	Hoary bat	Adult	Male	3.2	132	20 Sep
23 Sep	3	Red bat	Adult	Male	5.3	19	21 Sep
23 Sep	3	Red bat	Juvenile	Male	40.4	184	22 Sep

*Found during non-search related activities.