Results of Bat and Bird Mortality Monitoring at the

Expanded Buffalo Mountain Windfarm, 2005

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Executive Summary

The Buffalo Mountain Windfarm (BMW) was constructed in Anderson County, Tennessee in late 2000, and consisted of three Vestas V47 wind turbines. The Tennessee Valley Authority's (TVA) environmental review process identified bird mortality as a likely environmental impact at the windfarm, and TVA conducted a three-year study (September 2000-September 2003) to document bird mortality and activity at the windfarm; monitoring of bat activity and mortality was added after bat fatalities were also found. TVA documented a bird mortality rate of 7.3 birds/turbine/year and a bat mortality rate of 20.8 bats/turbine/year. Both of these mortality rates, which incorporate corrections for searcher efficiency, scavenging removal, and area searched, were high compared to other windfarms in the U.S.

In 2004, 15 additional turbines were constructed at BMW. These new turbines were larger than the three original turbines, and the magnitude of expected bird and bat mortality at the expanded windfarm was unknown. TVA conducted a second bird and bat mortality study during 2005, with the following objectives: 1) document bird and bat mortality at the original turbines and the new, larger turbines, and 2) compare results to the previous 2000-03 study.

Nine bird fatalities were recorded during searches at BMW in 2005, and the overall adjusted mortality rate was 1.8 birds/turbine/year. This rate is lower than those observed at BMW in previous years (7.3 birds/turbine/year), and similar to the national rate of 2.3 birds/turbine/year. All bird fatalities were songbirds, similar to fatalities at windfarms in West Virginia and Minnesota, but different from the numerous raptor fatalities observed at windfarms in the western U.S.

A total of 243 bats were found during searches in 2005, and the adjusted bat mortality rate at BMW was 63.9 bats/turbine/year, or an estimated 1,149 bats. This mortality rate is greater than the 2000-03 rate of 20.8 bats/turbine/year, considerably greater than the current national average of 3.4 bats/turbine/year, but similar in magnitude to a windfarm in West Virginia (47.5 bats/turbine/year).

Six species of bats were documented as fatalities at BMW during 2005. Eastern pipistrelle, red, and hoary bats were the most common species, making up 91% of the fatalities. None of the six species are listed as endangered or threatened. The majority of bat mortality (69%) occurred during late August and early September. This period coincides with the migratory season for bats. We also investigated correlations between mortality and environmental variables (wind speed and direction, temperature, pressure) and generation variables (generation, generation potential). None of these factors had significant associations with bat mortality.

Causes of bat mortality at windfarms are poorly understood. Turbine-specific factors (turbine lighting, height, and length of blades), likely relate to mortality. During 2005, no differences in bat mortality existed between turbines with and without lighting at BMW, but mortality rates differed between turbine types. Mortality rates were 35.2 and 69.6 bats/turbine/year at smaller and larger turbines, respectively. However, when mortality was measured per megawatt instead of per turbine, the smaller turbines had greater mortality (53.3 bats/megawatt/year) than the larger turbines (38.7 bats/megawatt/year).

Biotic factors, such as flight behavior of bats, their migration patterns, and aggregation of insect prey, may also contribute to bat mortality. An on-site radar study provided some insight into a few of these biotic factors, but more studies are needed to draw accurate conclusions.

Results of studies at BMW suggest that bird mortality at BMW is not a major cause for concern. However, the expansion of BMW has resulted in elevated levels of bat mortality that may be biologically significant for bats. Our findings mirror similar studies at other windfarms throughout the Appalachians, and suggest that a better understanding of bat mortality at wind turbines, and investigation of viable mitigation strategies, are needed in order to reduce levels of bat mortality.

Introduction

TVA constructed the first phase of Buffalo Mountain Windfarm (BMW) in late 2000, which consisted of three 0.66 megawatt (MW) Vestas V47 wind turbines. During TVA's environmental assessment of BMW, TVA and other agencies identified potential operational impacts to migratory birds (TVA 2000). In response to that concern, TVA initiated a three year study to document activity and mortality of birds at BMW. Documentation of bat mortality and activity was added to the study after bat fatalities were found during the first year (Fiedler 2004).

In 2004, TVA contracted with Invenergy TN LLC to purchase energy from the expansion of BMW with 15 larger, 1.8-MW Vestas V80 turbines (TVA 2002). Due to levels of bat mortality observed at the original turbines (Fiedler 2004, Nicholson 2003) and the larger size of the new turbines, TVA committed to document bat and bird mortality levels throughout the expanded windfarm. The objectives of this study were to: 1) document bird and bat mortality at both original and new turbines, and 2) compare results to the previous 2000-03 study and determine any changes associated with the expansion.

To meet study objectives, TVA performed systematic carcass searches to document mortality levels of birds and bats, examined temporal and spatial patterns of mortality, and determined species composition. All mortality estimates were adjusted for searcher efficiency, scavenger rate, and area searched.

Study Area

BMW is situated on Buffalo Mountain in Anderson County, located in the eastern part of Tennessee (Figure 1). The site is approximately five miles north of Oliver Springs, and 30 miles north of Knoxville. BMW is within the Cumberland Mountains at an elevation of about 1,010 m. The windfarm expansion extended north, west, and south of the original windfarm. The north expansion contains ten turbines along the northwest to southeast oriented Patterson ridge, the west expansion includes three turbines on a spur ridge oriented west to east, and the south expansion has two turbines situated on Windrock ridge near the original three turbines (Figure 2). Windrock ridge orients north-northwest to south-southeast. Table 1 compares the specifications of the two turbine types used at BMW.

BMW is located on a reclaimed surface mine and the habitat is relatively open, consisting of planted grasses, forbs and some trees and shrubs surrounding the gravel roads and turbine pads (Figure 3). The predominant habitat surrounding the site is mature and second growth oak-hickory forest (Figure 4). A small wetland (< 0.4 ha) left by mine reclamation activities exists ~75 meters east of the original three wind turbines. Many small, ephemeral pools and puddles exist on gravel roads and residual mine benches in the area, and provide concentrations of insects for bats and a source of water for all area wildlife.

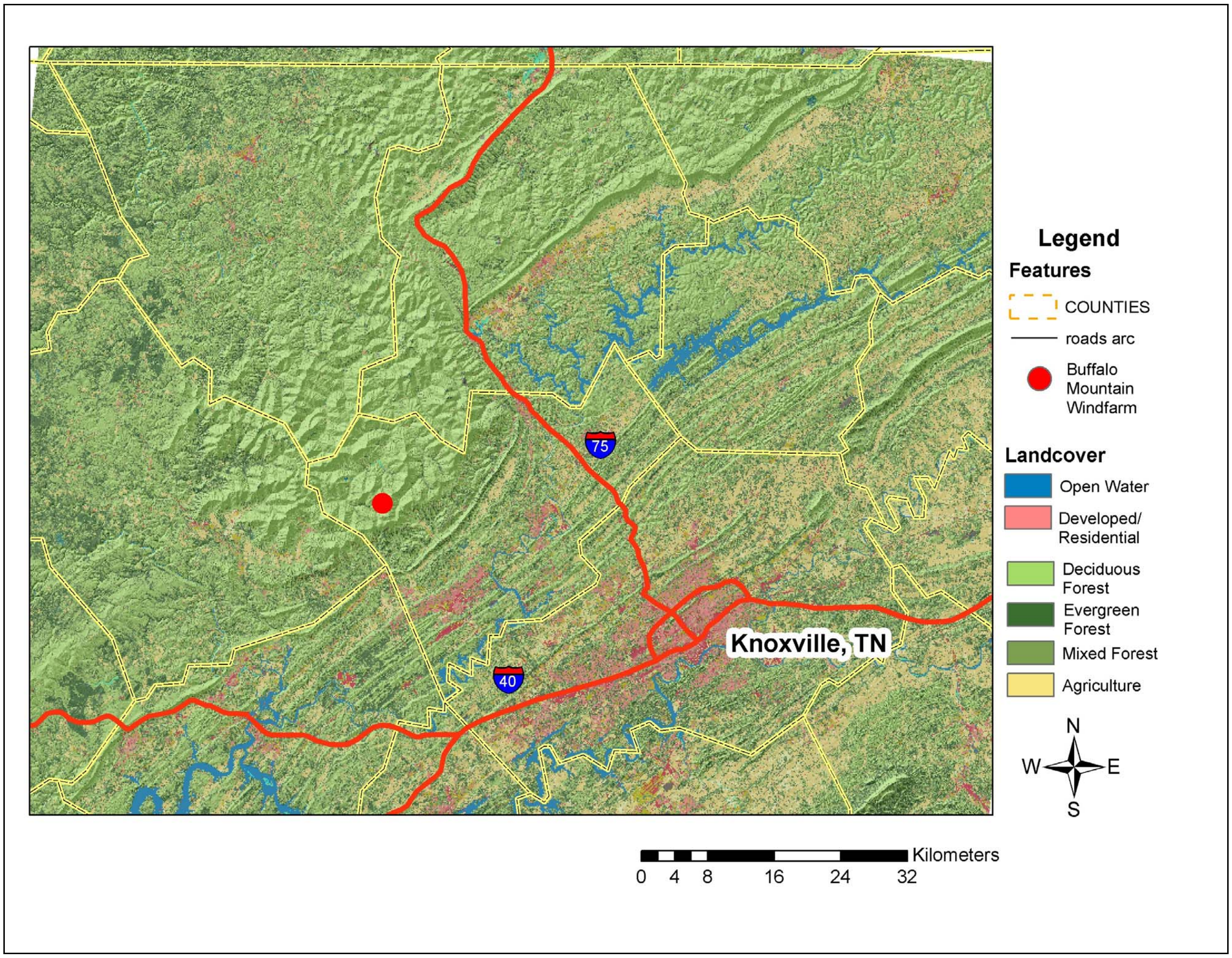

Figure 1. Landcover map showing location of Buffalo Mountain Windfarm in eastern Tennessee.

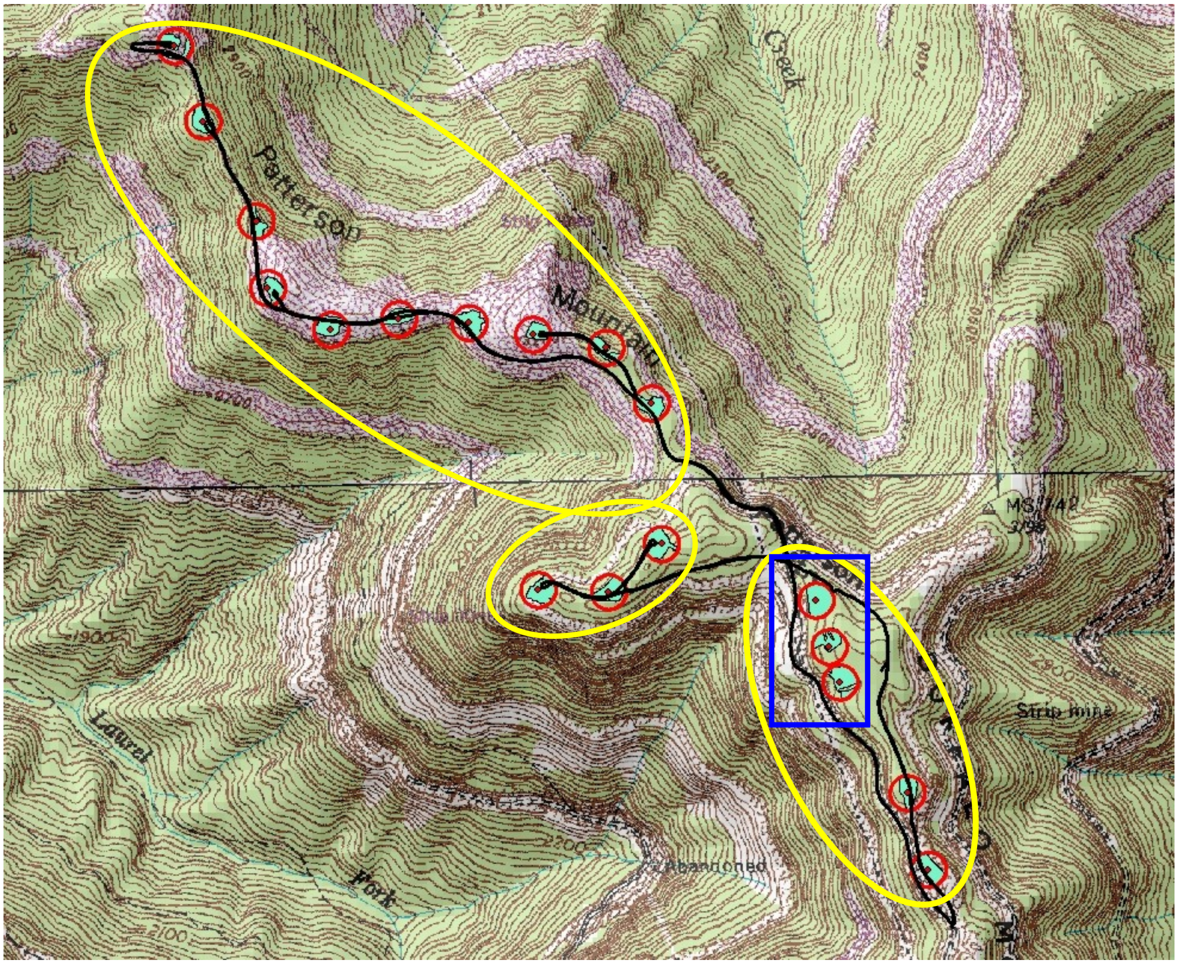

Figure 2. Distribution of wind turbines at Buffalo Mountain Windfarm. The circles denote Patterson ridge, the spur ridge, and Windrock ridge (top to bottom). The box contains the original three wind turbines on Windrock ridge.

Figure 3. The BMW site is located on a reclaimed surface mine, and has relatively open, ridgetop habitat

Figure 4. Mature and second-growth oak-hickory forest habitat surrounds much of BMW on adjacent ridges.

Table 1. Specifications for two types of wind turbines at Buffalo Mountain Windfarm.

	V47 Wind Turbines	**V80 Wind Turbines**
Turbine type	Vestas V47	Vestas V80
Generating capacity	660 kW (0.66 MW)	1,800 kW (1.8 MW)
No. turbines at BMW	3	15
Date Online at BMW	Sep 2000	Nov 2004
Blade length	75 ft or 23 m	139 ft or 42 m
Rotor Area	18675 ft^2 or 1735 m^2	54078 ft^2 or 5024 m^2
Tower Height (to nacelle)	213 ft or 65 m	256 ft or 78 m
Total Height (with blades)	290 ft or 88 m	395 ft or 120 m
Rotor swept heights above ground	136-290 ft or 42-88 m	131-394 ft or 40-120 m
Cut-in windspeed	9 mph or 4 m/s	10 mph or 5 m/s
Windspeed when full production starts	34 mph or 15 m/s	35 mph or 16 m/s
Cut-out windspeed	56 mph or 25 m/s	56 mph or 25 m/s
Rotor RPM's	28.5 rpm	16.5 rpm
Speed of blade tip	157 mph	152 mph
Lighting	Each with 2 white strobe	6 of 15 with red strobe

Methods

Carcass Searches

To monitor bat and bird mortality at BMW, we conducted weekly carcass searches from April-December, 2005. The site was not examined during January-March because no carcasses were observed during this period in the pervious study (Fiedler 2004, Nicholson 2003). Exceptions to the weekly search interval were 2-week search intervals in December, and 2-5 day search intervals from 23 August – 13 September during peak bat mortality. During each search, a 50-m circular plot around each of the turbines was systematically searched by a minimum of two observers. Within each plot, observers walked along linear transects spaced approximately 5-m apart. Only “searchable area” within each plot was examined, as some of the area was covered with dense vegetation, debris piles, rock outcrops, or was on excessively steep slopes. This was necessary for safety, and also allowed for relatively equal searcher efficiency in the areas deemed “searchable”. Searchable areas for each plot were marked by stakes, and the perimeter and searchable areas were recorded with a GPS unit.

When carcasses were found, the following data were recorded: date, turbine number, distance and bearing from turbine center, species, age, and gender. Extent of injury to each specimen and evidence of decomposition or scavenging were also noted. Specimens were assigned a unique code and then bagged, labeled, and frozen. A probable night or nights of death was estimated based on carcass decomposition, presence and size of insect eggs or larvae, and recent weather conditions.

Mortality Patterns

The following methods were used to examine patterns of mortality at the windfarm. Bats and birds were analyzed separately. Statistical analyses were conducted using Number Cruncher Statistical Systems™ (NCSS) 2001 statistical and data analysis system (Hintze 2001).

Temporal Patterns

We pooled fatalities for bats, birds, and for each bat species, into half-month groups to examine annual mortality patterns. Fatalities were pooled based upon estimated time of death, rather than date found. Seasonal comparisons were made using average daily mortality rate for each of the following periods: spring migration (5 April-15 May), summer residency (16 May-15 July), fall migration (16 July-30 September), and a period of little or no activity (1 October-20 December). These comparisons were calculated using the mean number of fatalities per day.

We also conducted modified carcass searches throughout five nights during peak mortality, and a portion of a sixth night, in order to pinpoint specific hours when bats were being killed. We estimated the time of death to the shortest time period possible based on regular searches at a few turbines, and condition of the bat when found (i.e. temperature, rigidity).

Spatial Patterns

The estimated numbers of bat fatalities per turbine were compared for three different ridges (V80 turbines only; ANOVA) and for turbines with and without lighting required by the Federal Aviation Administration (FAA) (all turbines; 2-sample t-test). Half of the turbines had FAA lighting; these included the three V47 turbines with white strobe lights and six V80 turbines with red strobe lights.

We calculated the average distance of carcasses from the center of each turbine. The numbers of carcasses found in eight cardinal directions were compared for all turbines, for each turbine type, and for each season.

Weather and Generation Associations

Weather data were collected from a meteorological tower at the BMW site. Wind speed (m/s) was gathered from a heated anemometer 47-m above ground, wind direction from a wind vane 40-m above ground, and temperature (C) and barometric pressure (mbar) from weather instruments three meters above ground. Ten-minute readings for these weather variables were averaged for each night (½ hour before sunset to ½ hour after sunrise) for August and September.

Generation potential was calculated as the proportion of a night that had wind speeds greater than 4 m/s. Hourly generation (kW) was also collected from V47 and V80 turbines separately. Some weather and generation measures were also gathered from individual V80 turbines, although data from the meteorological tower was used for all analyses unless otherwise noted. The V80 data included wind speed (m/s), direction of the nacelle, revolutions per minute (rpm), temperature (°C), and generation (kW); all were recorded as averages of 10-minute intervals.

The numbers of bat fatalities on nights with confirmed bat mortality were correlated with the nightly averages of wind speed, temperature, pressure, generation, and generation potential (Spearman correlation matrix). An ANOVA was used to determine if numbers of bat fatalities differed on nights categorized into one of four cardinal wind directions (north, east, south, west). The nightly averages of wind speed, temperature, pressure, and generation potential, along with total nightly generation during the 22 nights with known bat fatalities, were compared with the same variables on the remaining nights in August and September, when bat mortality was unknown (2-Sample T-test).

The annual estimated numbers of bat fatalities at each V80 turbine were correlated with the corresponding generation data, which was the sum of 10-min readings collected from individual V80 turbines during nights in August and September. These same generation data were also used to compare generation between turbines on the three different ridges (Patterson, spur, and Windrock; ANOVA).

Age, species, and gender

Bird species, age, and gender were determined using plumage coloration and wear according to Pyle (1997). Bat carcasses were identified according to Schwartz and Schwartz (1981). Age was determined using developmental changes in the cartilaginous growth plates of the fourth metacarpal-phalangeal joint (Anthony 1988). Bats were categorized as adult, sub-adult, juvenile, or unknown. Gender was based on external morphology for all species (Racey 1988).

<u>Mortality Estimates and Adjustments</u>

Mortality estimates were corrected for searcher efficiency and scavenging rates (SESR), and two area corrections that accounted for fatalities in plot areas not searched, and fatalities beyond the 50-m radius perimeter. Mortality estimates were not corrected for injured animals that moved out of the area before dying, as this correction is very difficult to make (Gauthreaux 1996). It was necessary to make the SESR corrections before the area corrections, as the calculated number of missed fatalities from areas not searched could not be assigned to specific time periods, which are needed to make the SESR adjustments.

Searcher Efficiency and Scavenging Removal (SESR) Corrections

A search bias trial was conducted on 2 August 2005 to determine the efficiency of our searchers and the scavenging rate of carcasses. Although SESR rates were estimated from six search bias trials during the 2000-03 study, vegetation cover was very different during the 2005 study. Vegetation at the V47 turbine plots changed from relatively open in 2000-03 to fairly dense in 2005. In contrast, the new V80 turbines were surrounded by relatively open ground due to the recent construction during 2004. Forty-eight carcasses were randomly placed within the searchable areas of search plots. Carcasses were labeled with tags attached to the wing and labels were hidden beneath the carcasses. During the initial search, carcass presence, condition, and evidence of scavenging on carcasses found were recorded, but the carcasses were not removed.

Written locations of planted carcasses were made available to searchers immediately following the initial search, and searchers attempted to locate all labeled carcasses not found to determine whether they had been missed or scavenged. Presence of these carcasses during subsequent searches was used to determine the amount of time a carcass remained on site. Based on decomposition rates observed on site, remaining carcasses were monitored for 20 days to encompass the amount of time a carcass was found to be available for scavenging.

Similar to the 2000-03 study, SESR rates were calculated from the search bias trial using methods presented by Erickson et al. (2003). However, once large numbers of bat fatalities began appearing in late August, scavenging increased dramatically (BMW maintenance personnel, personal communication), presumably because scavengers were being attracted to a new, persistent food source. Therefore, the scavenging rates calculated from the search bias trial were no longer accurate, and a new scavenging rate was calculated for this time period. To calculate the new rate, we used 76 bat fatalities found during searches on August 17th and 23rd (during peak mortality) and averaged the number of days each carcass was estimated to have been exposed before being found (Table 2).

Table 2. The estimated number of exposure days for 76 bat carcasses found during peak mortality (Aug 17 & 23), 2005 at BMW.

Estimated exposure days	**0.5**	**1.5**	**2.5**	**3.5**	**4.5**	**5.5**	**6.5**
Number of bats	26	24	8	9	6	2	1

Also similar to the 2000-03 study, the estimated number of bat fatalities within the 50-m radius search plots was calculated using methods from Mayer (1995) and Johnson et al. (2003b) (Fiedler 2004). This calculation incorporates the SESR rates, the adjusted scavenging for peak mortality, and the number of days between searches. Estimates were made for three time periods (5 April – 23 August, 25 August – 13 September, 20 September – 20 December), because carcass search frequency increased from the weekly searches during peak mortality, after which weekly searches resumed.

Scavenger Detection and Identification

Presence of scavenging was recorded for all carcasses. Potential scavengers were identified by observation of animals or their tracks at the BMW site and from motion-triggered cameras set near bait (bat or bird carcasses, sardines).

Area Corrections

Total number of observed bat fatalities was separated into 5-m increments (0-5m, 5.1-10m, 10.1-15m, etc.) for all turbines, but pooled by turbine type. We calculated percent of total observed fatalities within each 5-m annulus. These percentages were used to assign estimated percentages of SESR-adjusted bat fatalities to each annulus. Finally, the SESR-adjusted bat fatality numbers for each annulus were divided by the percent area searched in that annulus. We mapped the percent area searched using Trimble Navigation GPS units, and analyzed searchable area within ESRI ArcGIS software. For example, if 10% of observed bat fatalities were found in the 15.1-20 meter annulus for a turbine type, and the new total SESR-adjusted bat fatality number was 639, then 10% of

639 equals 63.9 SESR-adjusted bat fatalities for that annulus. Additionally, if 60% of the available area in that annulus was searchable, then 63.9 would be only 60% of the total number of bats in that interval. Therefore, 63.9 / 0.60 = 106.5 area-corrected bat fatalities for that annulus.

Area correction for fatalities beyond the 50-m radius plot perimeter was calculated using two alternative methods. Alternative A used the area-corrected numbers of fatalities within each annulus, while Alternative B calculated the density of SESR-adjusted fatalities / m^2 for each annulus. This density was calculated by dividing the number of SESR-adjusted fatalities for each annulus by area (in square meters) of that annulus. For both alternatives, the estimated numbers of fatalities within each annulus were plotted and fit with the trend line having the greatest r-squared value. This was done separately for both turbine types. The trend line equation was then used to predict the distance at which zero animals would occur, and the number of animals beyond the 50-m radius perimeter. The number of animals predicted beyond the 50-m radius perimeter was then added to the area-corrected number of animals found within the 50-m radius search plots.

Results

Carcass Searches

A total of 40 carcass searches were conducted from 5 April – 20 December, 2005, and we found 243 bats and 10 birds (Table 3). One bird and five bat carcasses were found outside the 50-m radius search perimeter and were excluded from all analyses. In addition, nine bats and one bird were observed at times other than carcass searches and were also excluded from all analyses. Percentage of searchable area in the 50-m radius plots ranged from 35% - 84% and averaged 51% (Table 4, Figure 5).

Mortality Patterns

Temporal Patterns

Only nine bird fatalities were found during searches in 2005 and no apparent temporal trend was observed (Table 5), although four were found in June. The remaining five were collected in May, July, September, and October.

Bat fatalities showed a distinct peak in late August with moderate numbers of fatalities in early August and early September (Table 5). Low levels of bat mortality also occurred from early April until the August peak, and from mid-September through mid-October. The distribution of the three most common bat species killed at BMW, red bat (*Lasiurus borealis*), eastern pipistrelle (*Pipistrellus subflavus*), and hoary bat (*L. cinereus*), generally followed the overall bat trend, with the majority of fatalities occurring in late August, although some individuals were killed before and after the late August peak (Figure 6). Two bat species only had one individual among the fatalities: a big brown bat (*Eptesicus fuscus*) in late August during peak migration, and a Seminole bat (*L. seminolus*) in early October. Unlike the other species, most silver-haired bats (*Lasionycteris noctivagans*) (15 of 18 fatalities) were killed during early April-June. The remaining three individuals were in September and October.

Table 3. Dates and results of carcass searches at BMW, 2005.

Carcass Search Date	No. Bats	No. Birds	Observers
5-Apr-05	0	0	JKF, MS
12-Apr-05	2	0	MS, AJT
19-Apr-05	6	0	JKF, MS
26-Apr-05	2	0	JKF, LGS, MS
4-May-05	0	2	LGS, JKF
10-May-05	4	0	LGS, JD
17-May-05	1	0	LGS, JKF
24-May-05	2	0	JKF, LGS, MS
31-May-05	2	0	LGS, JKF
7-Jun-05	4	1	LGS, MS
14-Jun-05	3	1	JKF, HH
21-Jun-05	1	1	LGS, AJT
28-Jun-05	2	1	LGS, JKF
5&6-Jul-05	4	0	LGS, JKF, EES
12-Jul-05	1	0	LGS, AJT
19-Jul-05	1	0	LGS, EES
26-Jul-05	5	1	LGS, JKF, JT
2-Aug-05	5	0	LGS, JKF
9-Aug-05	5	0	LGS, JKF
17-Aug-05	18	0	LGS, EES
*23-Aug-05	58	1	LGS, JKF, EES
*25-Aug-05	32	0	LGS, JKF, EES
*29-Aug-05	26	0	LGS, JKF, RM
*31-Aug-05	3	0	LGS, JKF, RM
*2-Sep-05	22	0	LGS, JKF, EES
*6-Sep-05	6	0	LGS, EES
*8-Sep-05	4	0	LGS, EES, SM, JJ
*13-Sep-05	12	0	LGS, EES
20-Sep-05	9	0	LGS, EES
27-Sep-05	0	1	LGS, EES
4-Oct-05	1	0	LGS, EES
11-Oct-05	2	2	LGS, JKF
18-Oct-05	0	0	LGS, EES
25-Oct-05	0	0	LGS, EES
1-Nov-05	0	0	LGS, EES
9-Nov-05	0	0	LGS, JKF, DF
15-Nov-05	0	0	LGS, EES
29-Nov-05	0	0	LGS, EES
6-Dec-05	0	0	LGS, EES
20-Dec-05	0	0	LGS, JKF
40 dates	243 bats	11 birds	

* More frequent searches during peak bat mortality

Table 4. Quantification of "searchable area" for search plots at each turbine and all turbines combined at BMW, 2005.

Turbine	50-m plot area (m^2)	area searched (m^2)	area not searched (m^2)	% plot area searched
1	7854	4120	3734	52%
2	7854	4057	3797	52%
3	7854	2834	5020	36%
4	7854	3109	4745	40%
5	7854	3815	4039	49%
6	7854	3330	4524	42%
7	7854	4428	3426	56%
8	7854	2712	5142	35%
9	7854	3025	4829	39%
10	7854	3660	4194	47%
11	7854	4838	3016	62%
12	7854	4357	3497	55%
13	7854	5234	2620	67%
14	7854	3630	4224	46%
15	7854	4288	3566	55%
t3	7854	4820	3034	61%
t2	7854	3302	4552	42%
t1	7854	6568	1286	84%
All Turbines	**141372**	**72127**	**69245**	**51%**

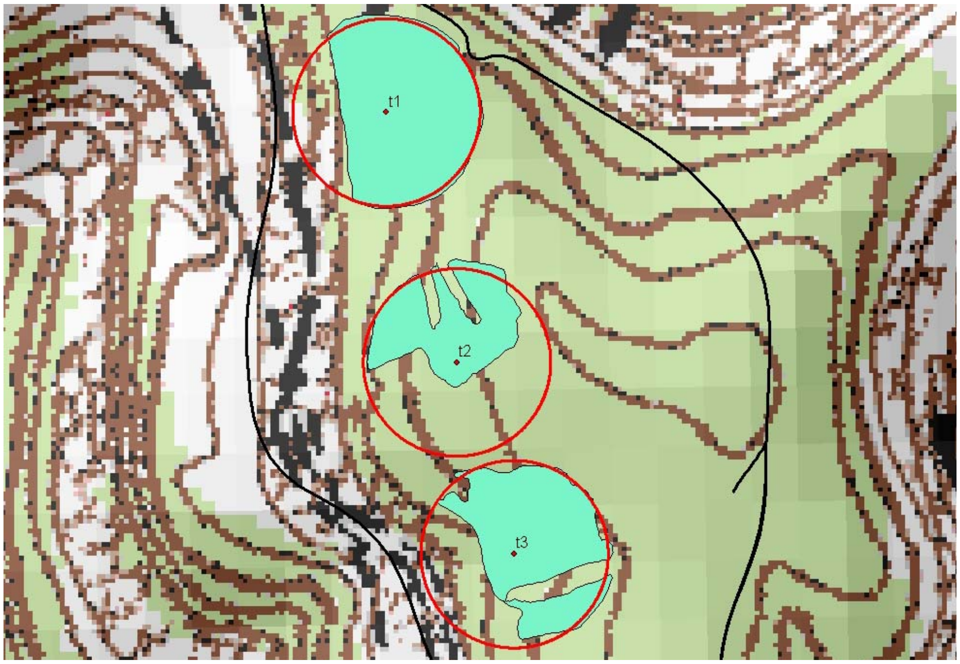

Figure 5. Only "searchable area" (aqua fill) was searched within the 50-m radius circular plots around each wind turbine at BMW during 2005.

Table 5. Bi-weekly distribution of bat and bird fatalities found at BMW, 2005.

	Bat fatalities		Bird fatalities	
	No.	**%**	**No.**	**%**
Apr 1-15	3	1.3%	0	0.0%
Apr 16-30	7	2.9%	0	0.0%
May 1-15	5	2.1%	1	11.1%
May 16-31	3	1.3%	0	0.0%
Jun 1-15	7	2.9%	2	22.2%
Jun 16-30	3	1.3%	2	22.2%
Jul 1-15	5	2.1%	0	0.0%
Jul 16-31	10	4.2%	1	11.1%
Aug 1-15	19	8.0%	0	0.0%
Aug 16-31	133	55.9%	0	0.0%
Sep 1-15	32	13.4%	0	0.0%
Sep 16-30	8	3.4%	1	11.1%
Oct 1-15	3	1.3%	2	22.2%
Oct 16-31	0	0.0%	0	0.0%
Nov 1-15	0	0.0%	0	0.0%
Nov 16-30	0	0.0%	0	0.0%
Dec 1-15	0	0.0%	0	0.0%
Dec 16-31	0	0.0%	0	0.0%

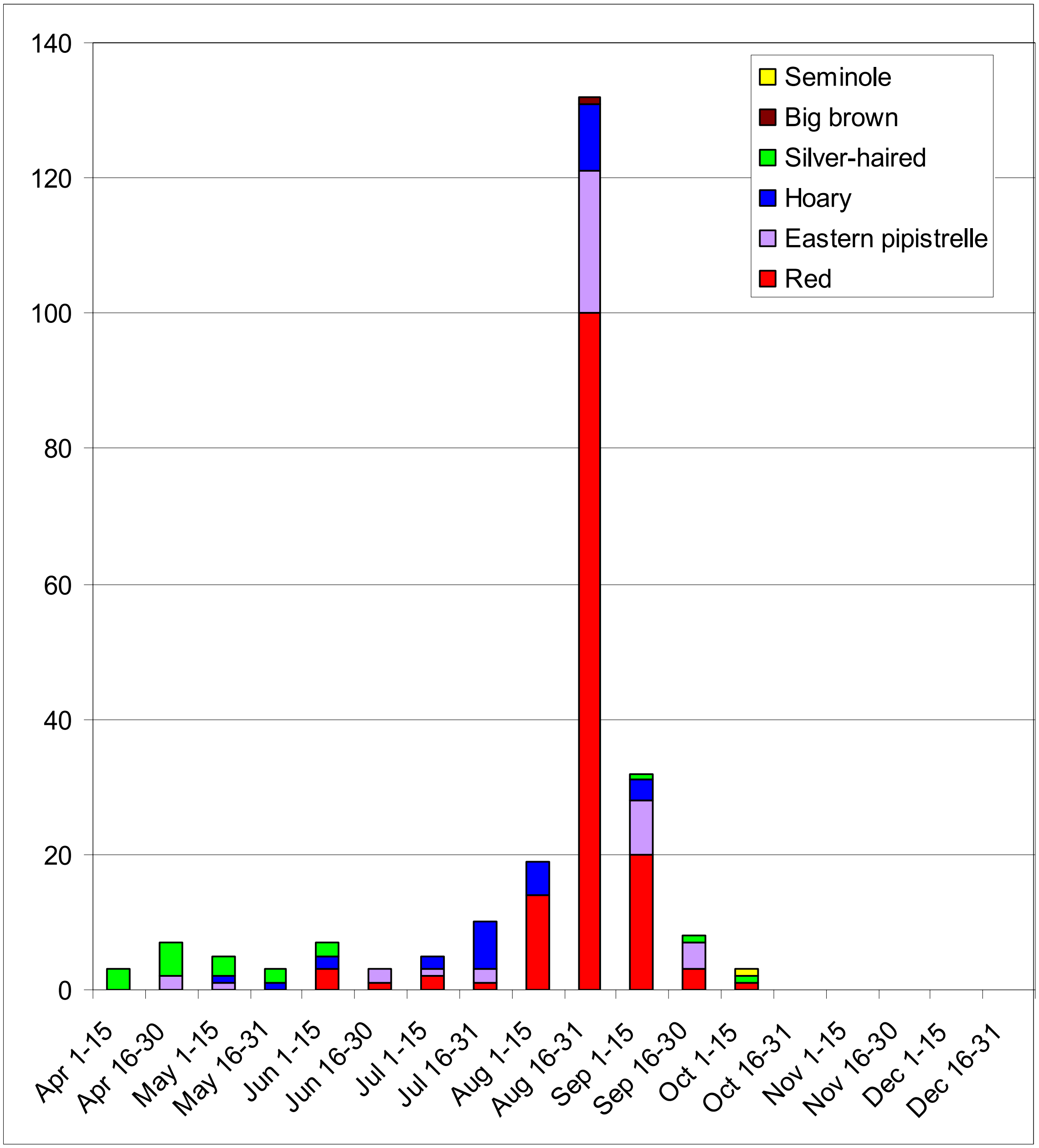

Figure 6. Bi-weekly distribution of six bat species killed at BMW, 2005.

Seasonal mortality rates varied among bats and birds (Table 6). Bird fatality rates were greatest during summer with equally low rates during the remaining seasons. The fatality rate for bats was greatest during fall migration and lowest during 1 October – 20 December. Equally low rates occurred during spring and summer for bats.

Table 6. Seasonal fatality rate of bats and birds at BMW, 2005. Numbers of animals are observed, and not corrected for search biases.

Season	No. days in season	No. bats in season	No. bat fatalities / day	No. birds in season	No. bird fatalities / day
5 Apr - 15 May	41	15	0.37	1	0.02
16 May - 15 Jul	61	18	0.30	4	0.07
16 Jul - 30 Sep	77	202	2.62	2	0.03
1 Oct - 20 Dec	81	3	0.04	2	0.02

No pattern in the time of bat mortality was observed during the six nights that repeated searches were conducted on a subset of turbines during peak mortality (Figure 7).

Spatial Patterns

The average distance of bird carcasses from the V47 turbines was 18.6 ± 8.3 meters (SE, n = 3), and 17.5 ± 8.5 meters (SE, n = 6) from the V80 turbines. The average distance of bat carcasses from the V47 turbines was 22.1 ± 2.9 meters (SE, n = 20), and 24.0 ± 0.7 meters (SE, n = 218) from the V80 turbines. Seven of the nine bird carcasses (78%) found during searches were north or northwest of turbines (Table 7). In contrast, bat carcasses were relatively evenly distributed in all directions from all turbines, from either turbine type, and during the four seasons, (Table 7). Percentage of bat carcasses in any of the eight directions ranged between 10.9% (NE) and 15.1% (SE).

Of the nine birds found in the plots, one each was found at V80 turbines 1, 5, 9, 10, two at V80 turbine 3, and three at V47 turbine T1. We saw no association between bird mortality and turbine type, and numbers of bird fatalities were too small for further analyses. The number of bat carcasses found within the 50-m radius plots after correcting for area not searched ranged from 3.8-15.4 at V47 turbines and 8.4-46.8 at V80 turbines (Figure 8). V80 turbines 6 and 7 were not operating during ~3 weeks of peak mortality, and estimated numbers of bat fatalities for these turbines are likely lower than if the turbines had been functioning. No other turbines experienced significant periods of downtime at night during August and September.

Using all turbines, the observed number of bird fatalities was greater on Patterson ridge (n = 6) than Windrock ridge (n = 3) or the spur ridge (n = 0). The average number of estimated bat fatalities at the 10 V80 turbines on Patterson ridge ($\bar{x}$ = 29.0) was also greater than at the 2 on Windrock ridge ($\bar{x}$ = 11.6), and slightly greater than at the 3 on the spur ridge ($\bar{x}$ = 23.4) (Figure 9). These differences were not significant (ANOVA; p = 0.24).

	Carcass	Carcass	Military time																							
Night	**Bearing**	**Distance**	2000	2030	2100	2130	2200	2230	2300	2330	2400	30	100	130	200	230	300	330	400	430	500	530	600	630	700	730	800
24-Aug-05	296	33.2																									
24-Aug-05	?	?																									
26-Aug-05	No fatalities found																										
27-Aug-05	188	7.1																									
27-Aug-05	18	21.8																									
27-Aug-05	56	32.5																									
27-Aug-05	62	28.7																									
27-Aug-05	72	28.5														238											
27-Aug-05	350	24.9																									
27-Aug-05	304	24																									
28-Aug-05	No fatalities found																										
31-Aug-05	135	7.7																									
31-Aug-05	316	12.9																									
31-Aug-05	69	11.1																									
31-Aug-05	112	5.7																									
31-Aug-05	105	9.3																									
31-Aug-05	216	29.1																									
31-Aug-05	228	27.8																									
31-Aug-05	180	33.4																									
31-Aug-05	60	17.8																									
31-Aug-05	110	10.2																									
1-Sep-05	159	32																									
1-Sep-05	45	20.7																									

Time period when a fatality occurred based on search times
Portions of the time period that a fatality most likely occurred, based on temperature of bat when found
Portions of the time period that a fatality probably did not occur, based on temperature of bat when found

Figure 7. Portions of night when bat fatalities were estimated as occurring based on regular, modified carcass searches at a few turbines during peak mortality at BMW, 2005.

Table 7. Number and percentage of bat and bird carcasses found in eight directions from the wind turbines at BMW, 2005.

Cardinal Direction	V47 Turbines		V80 Turbines		Both Turbine Types		1 Apr-15 May		16 May-15 Jul		16 Jul-30 Sep		1 Oct-31 Dec	
	No.	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**
Bats														
N	6	30.0%	24	11.0%	30	12.6%	3	21.4%	5	26.3%	22	10.9%		
NE	3	15.0%	23	10.6%	26	10.9%	2	14.3%	6	31.6%	18	8.9%		
E	2	10.0%	26	11.9%	28	11.8%	2	14.3%	2	10.5%	23	11.4%	1	33.3%
SE	5	25.0%	31	14.2%	36	15.1%	1	7.1%			35	17.3%		
S	3	15.0%	27	12.4%	30	12.6%	2	14.3%	2	10.5%	26	12.9%		
SW	1	5.0%	27	12.4%	28	11.8%	2	14.3%			26	12.9%		
W			30	13.8%	30	12.6%	2	14.3%	1	5.3%	25	12.4%	2	66.7%
NW			30	13.8%	30	12.6%			3	15.8%	27	13.4%		
Birds														
N	2	66.7%	2	33.3%	4	44.4%			2	50.0%	1	50.0%	1	50.0%
NE														
E														
SE														
S			1	16.7%	1	11.1%	1	100.0%						
SW														
W			1	16.7%	1	11.1%							1	50.0%
NW	1	33.3%	2	33.3%	3	33.3%			2	50.0%	1	50.0%		

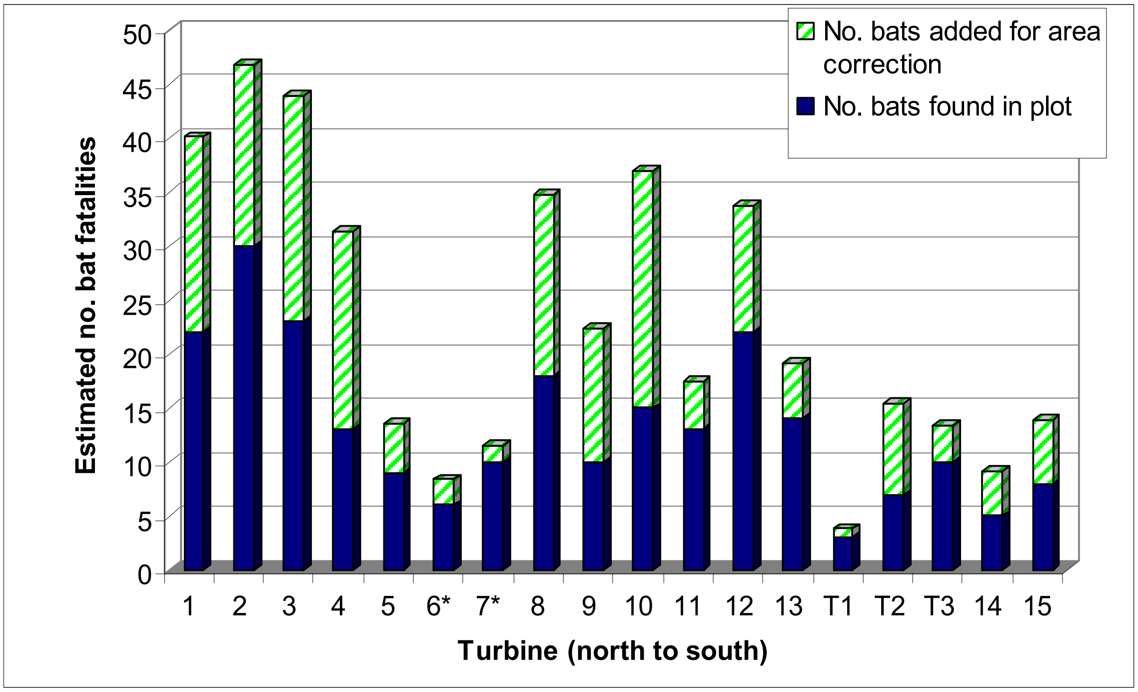

Figure 8. Estimated numbers of bat fatalities at each turbine plot, corrected for area not searched. Further additions of estimated numbers of bats missed due to scavenging and searcher efficiency were not made, as these corrections were equal across turbines. *(Turbines 6 and 7 experienced ~3 weeks of downtime during peak mortality.)

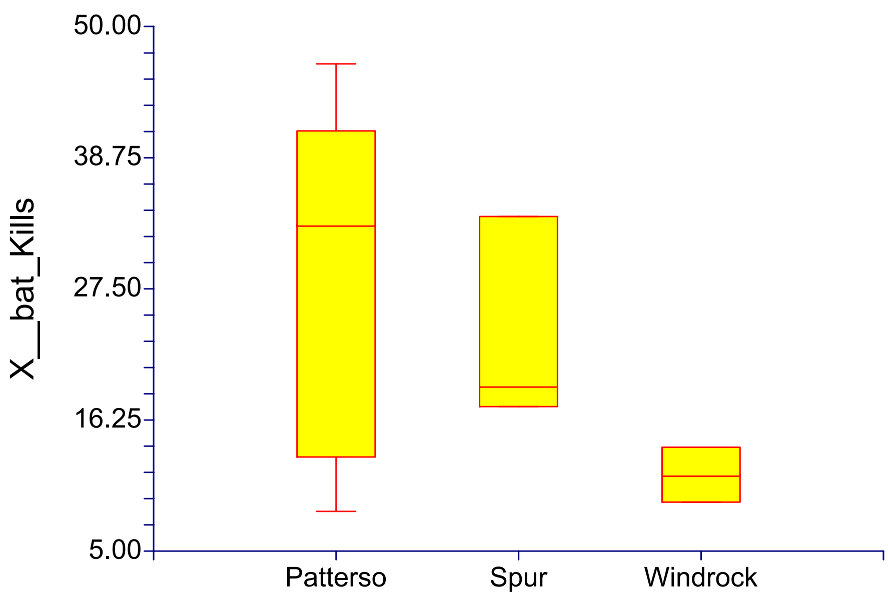

Figure 9. Box plot of average number of estimated bat fatalities per turbine on three ridges at BMW: Patterson (V80 turbines 1-10), Windrock (V80 turbines 14-15, V47 turbines 1-3, and the spur ridge between (V80 turbines 11-13). The box contains values between the 25th to 75th percentile and the median represented as a line. The outermost vertical lines represent minimum and maximum values.

A total of 4 birds and 99 bats were found at the turbines with lighting, while 5 birds and 139 bats were found at turbines without lighting. Bird fatality numbers were inadequate for statistical testing, but estimated numbers of bat fatalities at turbines with and without FAA lighting averaged 19.9 and 26.3 bats/turbine respectively, and were not significantly different (2-sampe t-test; $p = 0.33$).

Weather and Generation Associations

Bat mortality was confirmed on 22 nights during August and September. During these nights, numbers of bats killed were not strongly correlated with wind speed ($r = -0.14$, $p = 0.54$), temperature ($r = 0.30$, $p = 0.17$), barometric pressure ($r = -0.34$, $p = 0.12$), generation ($r = -0.08$, $p = 0.73$), or generation potential ($r = -0.09$, $p = 0.71$). These 22 nights were also classified into one of four prominent wind directions (north, east, south, west), and there were no differences in the numbers of bats killed in any of these categories (ANOVA; $p = 0.53$). On nights with known bat fatalities, the three weather variables and two generation measurements did not differ from the average values of the remaining nights in August and September when bat mortality was unknown (2-sample t-test; wind speed: $p = 0.38$, temperature: $p = 0.82$, pressure: $p = 0.93$, nightly generation: $p = 0.17$, generation potential: $p = 0.40$).

The estimated numbers of bat fatalities at each of the V80 turbines and the corresponding generation during August and September were graphed (Figure 10). Although the greatest bat mortality was at turbines with intermediate levels of generation (Figure 11), there was no correlation between number of bats killed and generation at an individual turbine ($r = 0.13$, $p = 0.63$). The amount of generation per turbine during August and September was greatest on the Windrock ridge, followed by the spur ridge and then Patterson ridge, however, these differences were not significant (ANOVA; $p = 0.17$).

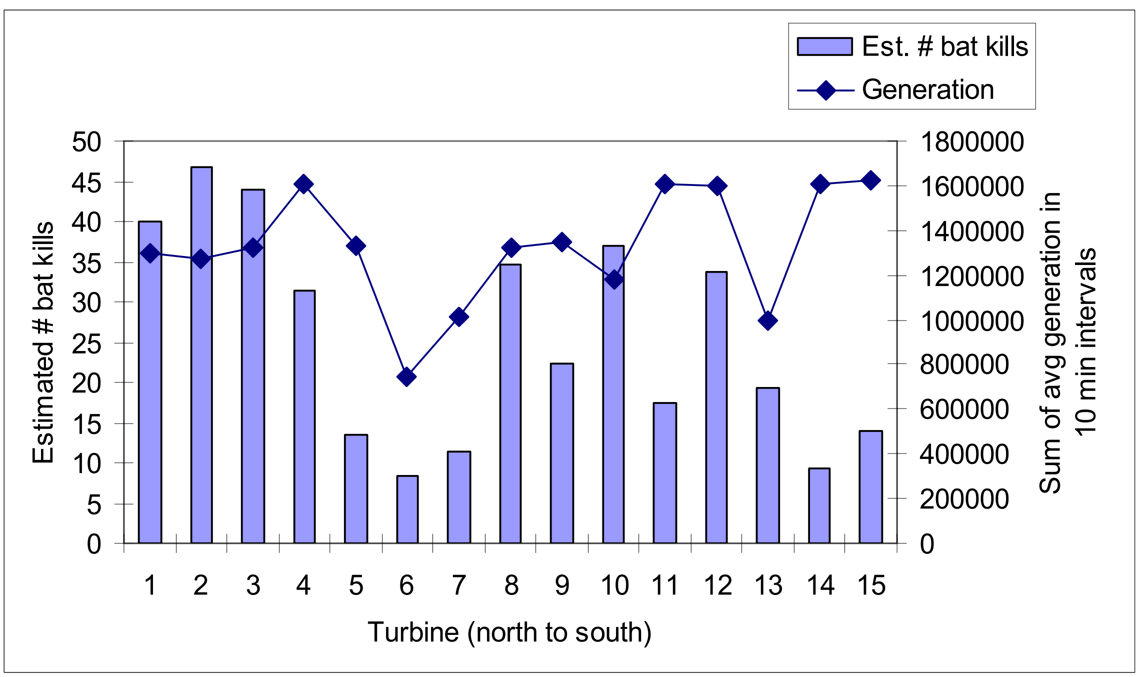

Figure 10. Estimated numbers of bats killed and the associated amount of generation, for each of the V80 wind turbines.

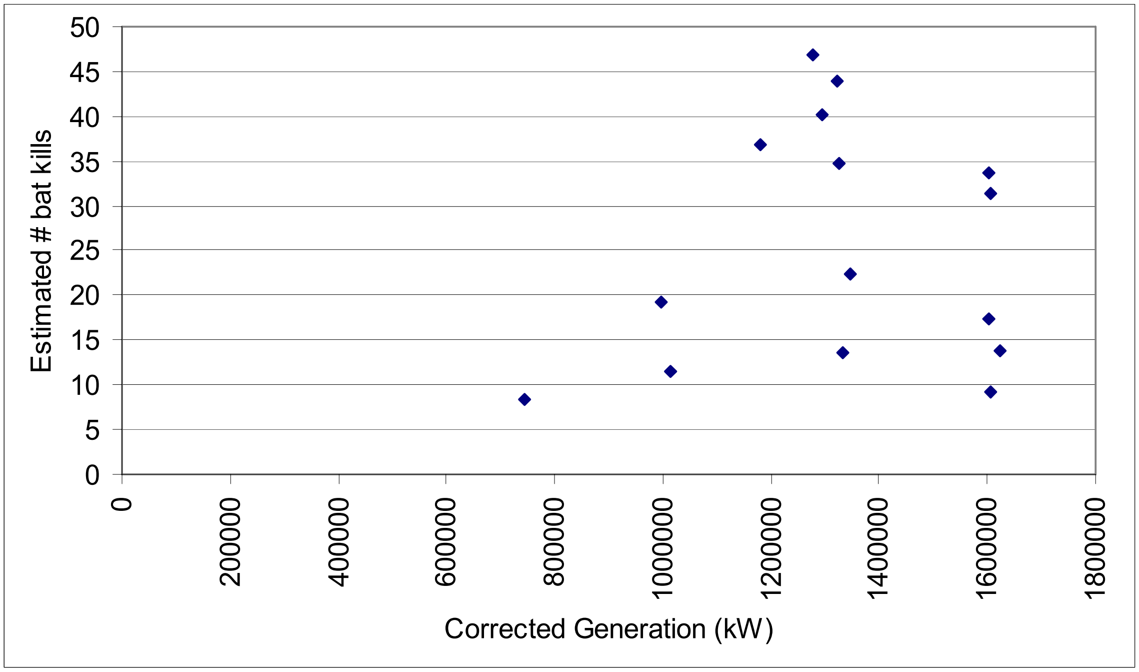

Figure 11. Relationship of number of bat fatalities and sum of generation at individual turbines on nights with confirmed bat mortality.

Age, species, and gender

Eight bird species were identified among the eleven fatalities found at BMW (Table 8). Two species had multiple fatalities: red-eyed vireo (n = 3) and rose-breasted grosbeak (n = 2). All were passerines (songbirds), and ten (91%) were migratory birds. A single tufted titmouse was the only non-migratory songbird, although the June and July dates of three red-eyed vireos and one blue-headed vireo indicate these migratory birds were probably breeding locally. Most bird fatalities consisted of adults (72.7%, n = 8).

Table 8. Species, age, and gender of bird fatalities at BMW, 2005.

Date	Common Name	Scientific Name	Age*	Gender
Found on Search				
4-May-05	Cerulean Warbler	*Dendroica cerulea*	Adult (AHY)	Female
7-Jun-05	Tufted Titmouse	*Baeolophus bicolor*	Adult (AHY)	Unknown
14-Jun-05	Red-eyed Vireo	*Vireo olivaceus*	Adult (AHY)	Unknown
21-Jun-05	Blue-headed Vireo	*Vireo solitarius*	Adult (SY)	Unknown
28-Jun-05	Red-eyed Vireo	*Vireo olivaceus*	Adult (ASY)	Unknown
26-Jul-05	Red-eyed Vireo	*Vireo olivaceus*	Adult (AHY)	Unknown
27-Sep-05	Rose-breasted Grosbeak	*Pheucticus ludovicianus*	Adult (AHY)	Female
11-Oct-05	Magnolia Warbler	*Dendroica magnolia*	Adult (AHY)	Male
11-Oct-05	Rose-breasted Grosbeak	*Pheucticus ludovicianus*	Juvenile (HY)	Female

Table 8 continued. Species, age, and gender of bird fatalities at BMW, 2005.

Date	Species		Age*	Gender
Found on Search, but beyond 50-m Radius				
4-May-05	Golden-crowned Kinglet	*Regulus satrapa*	Unknown	Female
Not Found on Search				
22-Aug-05	Ruby-throated Hummingbird	*Archilochus colubris*	Juvenile (HY)	Male

* Parenthesis contain the official age category according to Pyle et al. 1997. AHY = After Hatch Year, ASY = After Second Year, HY = Hatch Year, SY = Second Year

Six species were identified among the 238 bat fatalities found during searches at BMW during 2005 (Table 9, Figure 12), and were the same six species found during the 2000-03 BMW study (Figure 13). The red bat made up the majority of bat fatalities (60.9%), followed by eastern pipistrelle, and hoary bat. The remaining fatalities consisted of several silver-haired bats, and one each of big brown, Seminole, and an unidentified bat. Of the bats that could be aged, more adults were found than juveniles and sub-adults. However, if sub-adults were grouped with juveniles, as in the 2000-03 study, there would be more juveniles than adults. Of the bats on which gender could be determined, more males were found than females. Adult males were most numerous followed by juvenile females and juvenile males, and finally adult females (Table 9).

Mortality Estimates and Adjustments

Searcher Efficiency and Scavenging Removal (SESR) Corrections

In 2005, the average searcher efficiency rate at BMW was 41.2%. The average number of days for carcasses to be scavenged was 8.72 days (n = 48). This number differed among the two types of turbines. Carcasses were scavenged faster at V80 turbines (7.47 days, n = 43), than at the smaller V47 turbines (33.0 days, n = 5); largely due to thicker vegetation at the V47 turbines. Once large numbers of bat fatalities began appearing in late August and scavenging rates increased dramatically, a new scavenging rate of 1.9 days was calculated for the 23 August-13 September period.

Both searcher efficiency and scavenging rates were based on a search bias study using only bats, and the resulting rates were also used to estimate numbers of bird fatalities. Although differences may exist, Fiedler (2004) did not find significant differences between bat and bird carcasses for either rate during the 2000-03 study at BMW. Summaries for bats (Table 10) and birds (Table 11) are given for SESR rates, and observed and estimated numbers of fatalities during three time periods at V47 turbines, V80 turbines, and for all turbines combined.

Table 9. Age - gender categories for each species among the bat fatalities at BMW, 2005.

Species	Adult Male		Adult Female		Subadult Male		Subadult Female		Juvenile Male		Juvenile Female		Unknown		Total in species	
	No.	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**
Red	16	29.6%	8	34.8%	15	93.8%	10	83.3%	25	73.5%	32	88.9%	39	61.9%	145	60.9%
Eastern pipistrelle	18	33.3%	4	17.4%			1	8.3%	6	17.6%	2	5.6%	10	15.9%	41	17.2%
Hoary	13	24.1%	6	26.1%			1	8.3%	1	2.9%	1	2.8%	9	14.3%	31	13.0%
Silver-haired	7	13.0%	5	21.7%					1	2.9%	1	2.8%	4	6.3%	18	7.6%
Big brown									1	2.9%					1	0.4%
Seminole					1	6.3%									1	0.4%
Unknown													1	1.6%	1	0.4%
Total in Category	54	22.7%	23	9.7%	16	6.7%	12	5.0%	34	14.3%	36	15.1%	63	26.5%	238	100.0%

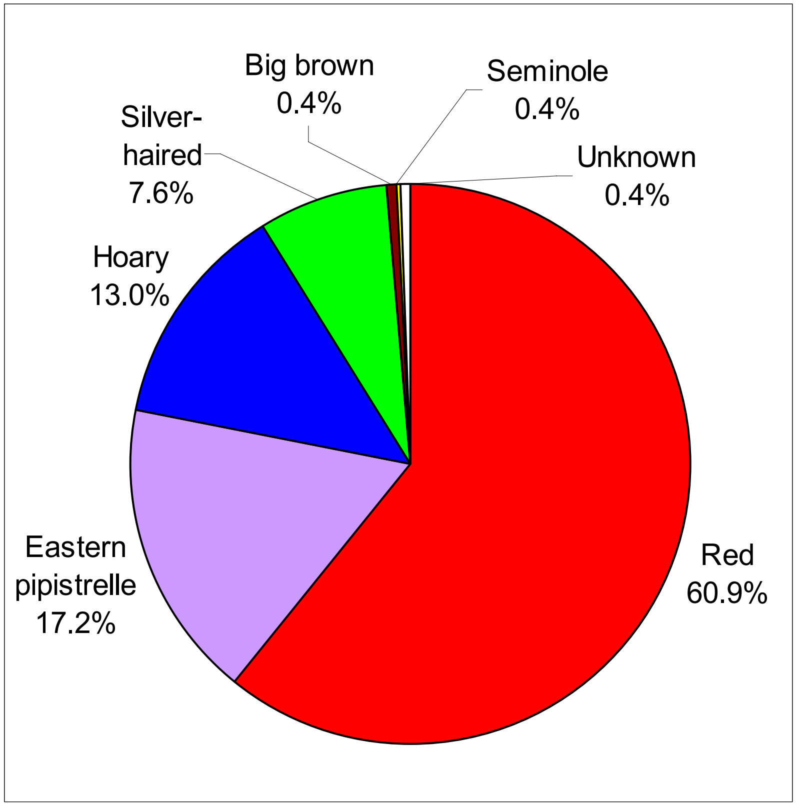

Figure 12. Species composition of bat fatalities at BMW, 2005.

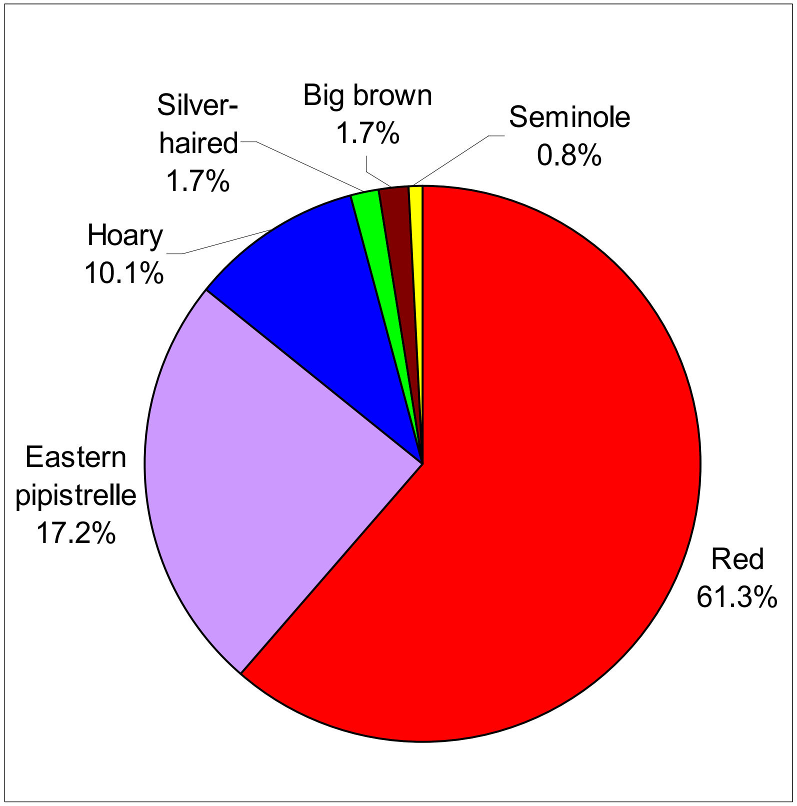

Figure 13. Species composition of bat fatalities at BMW, 2000-03.

Table 10. Searcher efficiency, scavenging rates, and numbers of observed and estimated bat fatalities at BMW for both turbine types and during three time periods, 2005.

Time Period	Search interval (days)	Searcher efficiency	Scavenging rate (days)	No. observed bat fatalities	No. estimated bat fatalities	Rounded estimate
1 Apr - 23 Aug (includes 23 Aug)						
V47 Turbines (n=3)	7	25.0%	33.0	9	7.6	9*
V80 Turbines (n=15)	7	43.3%	7.5	114	246.4	246
All Turbines (n=18)	7	41.2%	8.7	123	239.8	240
13 Sep - 31 Dec (excludes 13 Sep)						
V47 Turbines (n=3)	7	25.0%	33.0	0	0.0	0
V80 Turbines (n=15)	7	43.3%	7.5	12	25.9	26
All Turbines (n=18)	7	41.2%	8.7	12	23.4	23
23 Aug - 13 Sep (excludes 23 Aug, includes 13 Sep)						
V47 Turbines (n=3)	2	25.0%	1.9	7	29.5	30
V80 Turbines (n=15)	2	43.3%	1.9	53	128.7	129
All Turbines (n=18)	2	41.2%	1.9	60	153.4	153
V47 Turbines (n=3)	4	25.0%	1.9	4	33.7	34
V80 Turbines (n=15)	4	43.3%	1.9	28	136.0	136
All Turbines (n=18)	4	41.2%	1.9	32	163.6	164
V47 Turbines (n=3)	5	25.0%	1.9	0	0.0	0
V80 Turbines (n=15)	5	43.3%	1.9	11	66.8	67
All Turbines (n=18)	5	41.2%	1.9	11	70.3	70
Total for 2005						
V47 Turbines (n=3)				20	70.8	73
V80 Turbines (n=15)				218	603.9	604
All Turbines (n=18)				238	650.5	650

* Estimated number of fatalities in this category was less than observed number of fatalities, and we assume we found all fatalities.

Table 11. Searcher efficiency, scavenging rates, and numbers of observed and estimated bat fatalities at BMW for both turbine types and during three time periods, 2005.

Time Period	Search interval (days)	Searcher efficiency	Scavenging rate (days)	No. observed bird fatalities	No. estimated bird fatalities	Rounded estimate
1 Apr - 23 Aug (includes 23 Aug)						
V47 Turbines (n=3)	7	25.0%	33.0	1	0.8	1*
V80 Turbines (n=15)	7	43.3%	7.5	5	10.8	11
All Turbines (n=18)	7	41.2%	8.7	6	11.7	12
13 Sep - 31 Dec (excludes 13 Sep)						
V47 Turbines (n=3)	7	25.0%	33.0	2	1.7	2*
V80 Turbines (n=15)	7	43.3%	7.5	1	2.2	2
All Turbines (n=18)	7	41.2%	8.7	3	5.8	6
23 Aug - 13 Sep (excludes 23 Aug, includes 13 Sep)						
V47 Turbines (n=3)	2	25.0%	1.9	0	0.0	0
V80 Turbines (n=15)	2	43.3%	1.9	0	0.0	0
All Turbines (n=18)	2	41.2%	1.9	0	0.0	0
V47 Turbines (n=3)	4	25.0%	1.9	0	0.0	0
V80 Turbines (n=15)	4	43.3%	1.9	0	0.0	0
All Turbines (n=18)	4	41.2%	1.9	0	0.0	0
V47 Turbines (n=3)	5	25.0%	1.9	0	0.0	0
V80 Turbines (n=15)	5	43.3%	1.9	0	0.0	0
All Turbines (n=18)	5	41.2%	1.9	0	0.0	0
Total for 2005						
V47 Turbines (n=3)				3	2.5	3*
V80 Turbines (n=15)				6	13.0	13
All Turbines (n=18)				9	17.5	18

* Estimated number of fatalities in this category was less than observed number of fatalities, and we assume we found all fatalities.

Scavenger Detection and Identification

Nine potential species of scavengers were identified on the BMW site during 2005 (Table 12). American crow, a mouse species, and striped skunk were all observed scavenging carcasses. American crows were observed tearing bat carcasses apart, a mouse dragged an eastern pipistrelle carcass a few meters and left only the carcass skin (Figure 14), and a skunk was observed scavenging a bat carcass after removing the wings (Figure 15).

Table 12. Known and potential scavengers of bat and bird fatalities at BMW, 2005.

Common name	Scientific name	Observed scavenging carcasses	Detected by motion-triggered camera	Evidence observed on site
American crow	*Corvus brachyrhynchos*	x	x	x
turkey vulture	*Cathartes aura*			x
black vulture	*Coragyps atratus*			x
bobcat	*Lynx rufus*		x	x
coyote	*Canis latrans*			x
red fox	*Vulpes vulpes*		x	
striped skunk	*Mephitis mephitis*	x	x	x
mouse species	*Peromyscus spp.*	x	x	
raccoon	*Procyon lotor*		x	x
timber rattlesnake	*Crotalus horridus*			x
Black Ratsnake	*Elaphe obsoleta*			x

Figure 14. The remains of an eastern pipistrelle carcass after scavenging by a mouse species.

Figure 15. Bat wings were observed at the BMW site during 2005, attributed to scavenging by skunks.

Area Corrections

After applying searchable area corrections for bats, 105.6 bat carcasses were estimated for the V47 turbines and 1043.7 carcasses for the V80 turbines (Table 13). The small number of bird fatalities made it unreasonable to estimate area corrections within each 5-m annulus. Therefore, we corrected the SESR-adjusted bird fatality numbers using total percent of searchable area for both turbine types (V47 = 62.3% and V80 = 48.8% plot area searched). Searchable area corrections for bird fatalities were estimated as 4.8 for the V47 turbines and 26.7 for the V80 turbines.

The estimated numbers of bats occurring beyond the 50-m perimeter of the search plots was calculated two different ways. Alternative A fit a trend line to the estimated numbers of bat fatalities occurring in each 5-m annulus, while alternative B fit a trend line to the density of estimated bat fatalities in each 5-m annulus (per square meter). Because too few bird fatalities were found to develop distance curves for each turbine type, this final area correction was not made for birds.

For alternative A, polynomial trend lines fit the data best for estimated number of bat fatalities at the V80 turbines (r^2 = 0.92), and the V47 turbines (r^2 = 0.19, Figure 16), although the low r-squared value of the V47 data is most likely from a low sample size (n = 20 carcasses). The polynomial equations predicted bat fatalities would reach zero at a distance of 59.6 meters from the V80 turbines, and 56.1 meters from the V47 turbines. Small adjustments to the estimated numbers of bat fatalities would be needed for both the V47 turbines (+1.01 bats) and the V80 turbines (+45.28 bats, Table 14).

Table 13. Corrections in number of bat fatalities in each 5-m annulus for areas not searched in plots.

5-m annuli	Total area in annulus	% area searched in annulus		No. bats observed during searches		% estimated bats in each annulus		No. SESR-corrected bats in each annulus		No. bats after searchable area correction	
		V47 turbines	V80 turbines	V47 turbines	V80 turbines	V47 turbines	V80 turbines	V47 turbines	V80 turbines	V47 turbines	V80 turbines
0-5	81	100.0%	100.0%	3	5	15.0%	2.3%	11.0	13.9	11.0	13.9
5.1-10	236	100.0%	98.0%	2	18	10.0%	8.3%	7.3	49.9	7.3	50.9
10.1-15	392	89.1%	89.5%	2	24	10.0%	11.0%	7.3	66.5	8.2	74.3
15.1-20	548	76.9%	81.0%	2	37	10.0%	17.0%	7.3	102.5	9.5	126.5
20.1-25	704	65.7%	72.3%	2	42	10.0%	19.3%	7.3	116.4	11.1	161.1
25.1-30	860	57.4%	60.8%	3	27	15.0%	12.4%	11.0	74.8	19.1	123.0
30.1-35	1032	56.6%	49.8%	1	29	5.0%	13.3%	3.7	80.3	6.5	161.2
35.1-40	1172	55.6%	37.3%	4	18	20.0%	8.3%	14.6	49.9	26.2	133.5
40.1-45	1336	54.1%	28.8%	1	12	5.0%	5.5%	3.7	33.2	6.8	115.4
45.1-50	1489	43.1%	19.8%	0	6	0.0%	2.8%	0.0	16.6	0.0	84.0
total # bats				20	218			73.0	604.0	105.6	1043.7

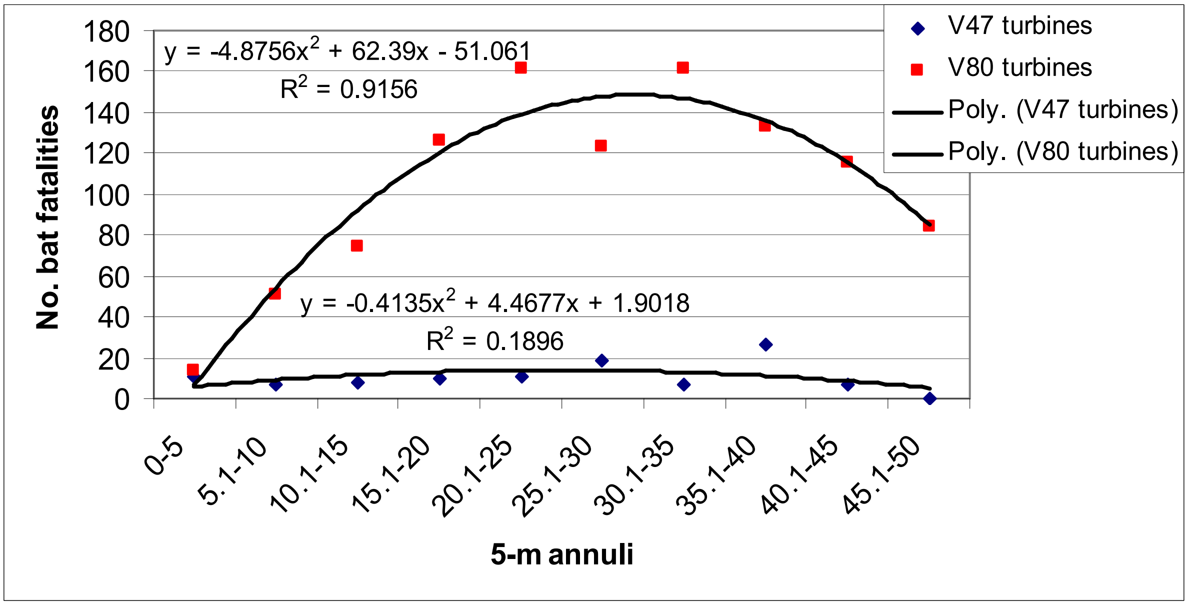

Figure 16. Number of bat fatalities found in 5-m annuli around both turbine types, associated trend lines, and r^2 values.

Table 14. Number of bat and bird fatalities estimated at BMW after each of four corrections, adjusting for searcher efficiency and scavenger removal (SESR), area not searched within plots, and potential fatalities beyond the 50-m radius plot perimeter.

	V47 turbines (n=3)	V80 turbines (n=15)	All turbines (n=18)
Number bats:			
Observed	20	218	238
after SESR-correction	73	604	677
after searchable area correction	105.6	1043.7	1149.3
after area-correction (Alt. A)	106.6	1089.0	1195.6
after area-correction (Alt. B)	105.6	1043.7	1149.3
Number birds:			
Observed	3	6	9
after SESR-correction	3	13	18
after searchable area correction	4.8	26.7	31.5
after area-correction (Alt. A)	na	na	na
after area-correction (Alt. B)	na	na	na

For alternative B, a polynomial trend line fit the data best for estimated density of bat fatalities at the V80 turbines ($r^2 = 0.87$), but a logarithmic trend line fit the V47 data best ($r^2 = 0.69$, Figure 17). The alternative B equations predicted that the density of bat fatalities would reach zero at 42.2 meters for the V47 turbines, and 54.4 meters for the V80 turbines. Additional corrections were not necessary for either turbine type, as both reached a density of zero before the 55-m category (Table 14).

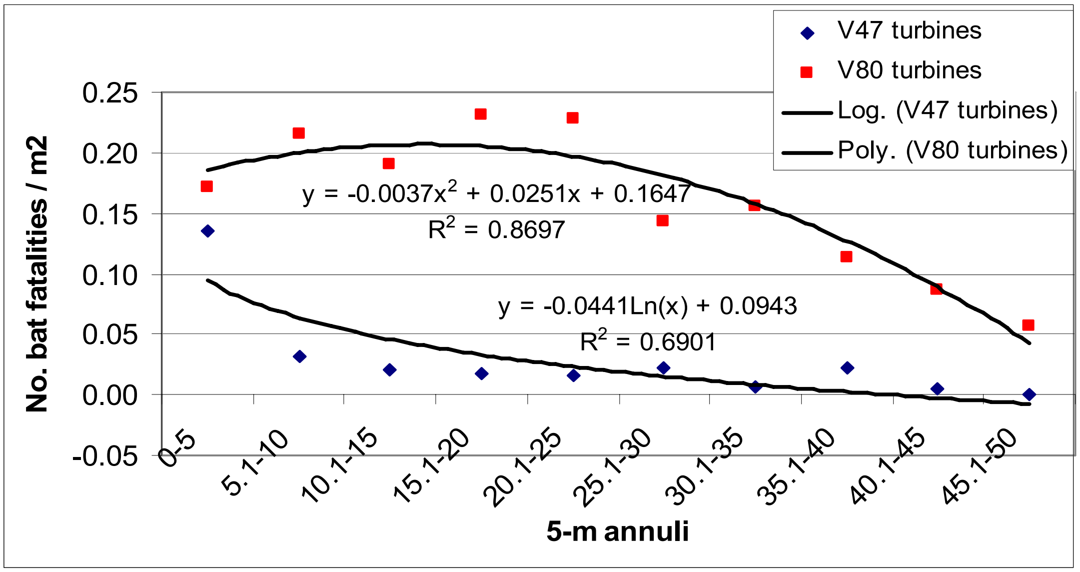

Figure 17. Density of bat fatalities found in 5-m annuli around both turbine types, associated trend lines and r^2 values.

The final area correction from alternative B was chosen to calculate the final bat mortality rates, as they were comparable to methods used during the 2000-03 study at BMW (Fiedler 2004) and required less adjustment. The final bat and bird mortality rates are expressed three ways: estimated number of fatalities per turbine per year, estimated number of fatalities per megawatt of generating capacity per year, and estimated number of fatalities per square foot of rotor area per year (Tables 15 & 16).

Table 15. Final bat mortality estimates for both turbine types and all turbines combined at BMW for 2005.

	V47 turbines (n=3)	**V80 turbines (n=15)**	**All turbines (n = 18)**
Observed no. bat fatalities (1 Apr - 31 Dec, 2005)	20	218	238
Estimated no. bat fatalities (1 Apr - 31 Dec, 2005)	105.6	1043.7	1149.3
No. estimated bat fatalities / Turbine / Year	35.2	69.6	63.9
No. estimated bat fatalities / Megawatt / Year	53.3	38.7	39.7
No. estimated bat fatalities / ft^2 of Rotor Area / Year	1.89E-03	1.29E-03	1.33E-03

Table 16. Final bird mortality estimates for both turbine types and all turbines combined at BMW for 2005.

	V47 turbines (n=3)	V80 turbines (n=15)	All turbines (n = 18)
Observed no. bird fatalities (1 Apr - 31 Dec, 2005)	3	6	9
Estimated no. bird fatalities (1 Apr - 31 Dec, 2005)	4.8	26.7	31.5
No. estimated bird fatalities / Turbine / Year	1.6	1.8	1.8
No. estimated bird fatalities / Megawatt / Year	2.4	1.0	1.1
No. estimated bird fatalities / ft2 of Rotor Area / Year	8.59E-05	3.29E-05	3.63E-05

Discussion

Avian Mortality

Nine bird fatalities were recorded during searches at the expanded BMW during 2005. After corrections for scavenging, searcher efficiency, and area searched, the overall avian mortality rate at BMW was 1.8 birds/turbine/year. This rate is lower than the mortality rate (7.3) found at BMW during the previous 2000-03 study (Nicholson et al. 2005), but similar to the current national rate of 2.3 (NWCC 2004). Other avian mortality studies at windfarms in the east include two windfarms in Vermont and Pennsylvania (Erickson et al. 2002), where no bird fatalities were observed during a year of monitoring, a 7-turbine windfarm in New York with four turbine casualties (Kerlinger 2002), and a 44-turbine windfarm in West Virginia with a rate of 4.0 birds/turbine/year (Kerns and Kerlinger 2004).

All bird fatalities were passerines (songbirds), similar to the composition of bird fatalities at BMW during 2000-03, and at windfarms in West Virginia and Minnesota, but different from the predominantly raptor species fatalities at windfarms in the western U.S. (Erickson et al. 2001, Kerns and Kerlinger 2004). Also similar to other studies in the eastern U.S., many of the bird fatalities occurred during spring migration (18.2%) or fall migration (45.4%), but 36.4% of bird fatalities in our study were also found during the breeding season. The dramatic increase in scavenging during the peak bat mortality period may be an explanation for the low numbers of bird fatalities found during fall migration, and have consequently inflated the proportion of resident birds killed.

Avian mortality at the expanded BMW and other windfarms in the eastern and upper midwestern U.S. is much lower than bat mortality at these sites, and also lower than bird mortality at communication towers. Factors often associated with mortality events of large numbers of birds include constant lighting, very tall structures, guy wires, and inclement weather during bird migration (Shire et al. 2000). A multiple-fatality event at the Mountaineer Wind Energy Center in West Virginia during a single night in 2003 was unusual among windfarms, and was attributed to a combination of heavy fog and sodium vapor lights on a nearby substation (Kerns and Kerlinger 2004). Half the turbines at BMW have flashing lights and bird mortality was similar at turbines with and without FAA lighting. Avian mortality rates for both turbine types were similar (1.6 for V47 turbine, 1.8 for V80 turbines), but the small number of bird casualties prevents us from determining if turbine size affects avian mortality rates at BMW. The small number of casualties also prevented any analysis of relationships between fatalities and weather or generation variables.

Bat Mortality

The bat fatalities observed during this study were of six species; none are listed as endangered or threatened species. Red, hoary, and eastern pipistrelle bats were most common and represented 91% of the fatalities. Red, hoary, and silver-haired bats are all tree roosting, migratory bat species (Barbour and Davis 1969), and have been commonly found at other midwest and eastern windfarms (Johnson et al. 2003, Arnett, 2005). Eastern pipistrelle, although not as migratory, exhibits autumn dispersal and is one of the most common species in the eastern U.S. Big brown bats are common throughout the country and have been found at most windfarms, although never in great numbers. The presence of a Seminole bat among the fatalities is unusual, as BMW is north of the southeastern coastal plain where this species commonly occurs; the BMW fatality was probably an individual exhibiting autumn dispersal (Kennedy et al. 1984). This species has not been reported from other windfarms, but two fatalities were found at BMW in 2003.

The bat mortality rate at the expanded BMW during 2005 was 63.9 bats/turbine/year; currently the highest documented rate reported in the U.S. This rate is an order of magnitude greater than the national average of 3.4 (NWCC 2004), but similar in magnitude to a windfarm in West Virginia (47.5, Kerns and Kerlinger 2004). The large number of bats estimated to have been killed at BMW (1149 during 2005), and at other windfarms in the eastern U.S., are a concern.

Specific reasons for bat mortality at windfarms are poorly known, but the fall peak in bat mortality observed at BMW and other windfarms (Arnett 2005, Johnson 2003) suggests fall migration is a key factor. Although not documented at other windfarms or during the 2000-03 BMW study, spring migration may also be a factor for at least one species. A small mortality peak of bats occurred at BMW during late spring and early summer 2005, and consisted predominantly of silver-haired bats. While the majority of bat mortality occurred during fall migration with a small peak observed during spring migration, a low level of bat mortality occurred throughout the summer. Certain conditions during fall migration may contribute to bat mortality more than others; variables considered during this study include various weather conditions, time of night, turbine lighting, turbine location, turbine type, and turbine generation.

During the searches conducted throughout a few nights during peak mortality, bat mortality was scattered throughout sample nights, with no apparent time periods of either high or low mortality. However, sample size and number of nights were small and may have obscured a pattern.

Lights on tall structures are often a factor in large bird mortality events, but this does not seem to be the case for bat mortality at BMW as there was no difference in bat mortality at turbines with and without FAA lighting. To date, no other windfarms have found turbine lighting to be a factor for bat mortality (Erickson et al. 2002, Arnett et al. 2005).

The position of turbines within a windfarm, especially related to topography, may affect mortality at individual turbines. Although fatalities were greatest at three turbines on the long, narrow Patterson ridge, the mortality rate on this ridge did not significantly differ from the other ridges.

Turbine type may also be useful in predicting bat mortality levels. The mortality rate at the larger V80 turbines (69.6) was almost twice as great as the smaller V47 turbines (35.2), but bat mortality rates measured per megawatt rather than per turbine were greater at the smaller V47 turbines (53.3) than the V80 turbine (38.7). These differences in turbine types and mortality rates may be important for future windfarm developers to consider.

Both studies at BMW found little relationship between mortality and variables related to generation. Fiedler (2004) found that the late summer/early fall peak in bat mortality coincided with the period of lowest winds and lowest electrical generation at Buffalo Mountain during 2000-03. On a nightly basis, the amount of daily generation was strongly correlated with wind speed; however, daily generation was a poor predictor of bat mortality during this period. During 2005, the greatest bat mortality was at turbines with an intermediate amount of generation. On a nightly basis however, there was no correlation between number of bat fatalities and either nightly turbine generation or nightly generation potential (nights with wind speeds > 4 m/s).

As for weather variables, bat mortality during 2000-03 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 (Fiedler 2004). Our frequency of searches often made it difficult to assign carcasses to a specific night during the 2000-03 study and affected the resolution of analyses with weather data. This difficulty continued in 2005, even when carcass searches were increased in frequency from weekly to every 2-5 days during peak mortality, and we found no associations between bat mortality and any weather variable during 2005. Results from our studies as well as other windfarm studies illustrate the need for increased temporal resolution of mortality, weather variables, and generation data. Increasing search frequency to daily, or even several searches throughout the night, would increase our accuracy at pinpointing the time of death for carcasses, which in turn, would provide the needed resolution.

Radar Study

A radar analysis of bat movement at BMW was conducted by DeTect, Inc. during the peak mortality period in 2005. Goals were to assess flight behavior of bats in and around the windfarm, to judge whether the bats were feeding in the area or flying straight-line paths suggesting migration, and to determine whether they were reacting to the turbines. Both horizontal (S-band) and vertical (X-band) radar data were collected from 23 August to 1 September 2005. Preliminary results of this study suggest that bats move generally north to south through BMW during migration, that southerly winds reduce the number of bats in the air, and that flight paths are complex (which suggest feeding during flight).

The radar study also attempted to quantify the number of bats moving through BMW using the X-band sweep beam vertical radar. Bat numbers ranged from less than 100 to more than 500 per hour (DeTect, Inc. 2006). These data suggest hundreds to thousands of bats may move through BMW nightly from the middle of August to the middle of September. Based on this preliminary estimate, mortality at BMW likely represents a small percentage of the total number of bats passing through the area. However, mortality of even a small percentage of the population can result in additive mortality through time and across the landscape, which could lead to an overall adverse impact.

Although the radar analyses provided insight into bat movements, the ability to determine the number of bats may be limited. The erratic flight behavior of foraging bats often caused the radar to lose tracking on individual targets, resulting in the possibility of counting the same bat as two or more different bats and possibly overestimating the numbers of bats present. The horizontal data is very useful for looking at flight paths, but it is not useful for determining numbers of bats unless new algorithms can be developed to more accurately track individual targets. The vertical radar data shows promise for continuous tracking of targets and more accurate estimates of numbers of bats.

In addition to the sweep beam vertical radar used at BMW, fixed-beam vertical radar has been used to observe birds during migration. With fixed-beam vertical radar, bird signatures are typically represented by straight lines, while bats are represented by erratic targets (Gauthreaux and Livingston 2006). However, Gauthreaux and Livingston (2006) indicated that fixed beam radar techniques may not differentiate between birds and non-foraging bats.

Results of the radar investigation are preliminary. The number of bats moving through an area has not been previously measured or validated using these methods, and factors leading to both over- and underestimation are present. While these radar data are intriguing, more time and study is needed to determine the validity of using this method to measure bat numbers.

Implications

Although bird mortality at BMW is likely not resulting in measurable population- or species-level impacts, the much higher levels of bat mortality are of concern. The mortality rate of bats at BMW is higher than those reported from other U.S. windfarms. Solutions for reducing bat mortality at wind turbines are under development. These include acoustical deterrents, feathering blades during low wind periods, and increasing the cut-in wind speed for blade rotation. The next step will be exploring one or all of these options as effective methods in reducing bat mortality at windfarms. Although enough information has been gathered to determine that bat mortality is an issue for the wind industry, more detailed information is needed. Future studies should attempt to identify narrow bands of time in nights during fall migration when mitigation measures, which could also include stopping blade rotation, may be most effective. This information would be used in conjunction with the methods proposed for reducing bat mortality.

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