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Regional Analysis of Wind Turbine-caused Bat and Bird Fatality

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Executive Summary

Wind energy has been the fastest-growing renewable energy source for electricity in the United States. Many studies have estimated avian and bat fatalities at wind turbine facilities. However, direct comparisons of the results of these studies is difficult and can be misleading due to the numerous differences in the study protocols and the methods used to develop a final estimate of fatality. We had a unique opportunity to compare the fatality estimates from 3 wind energy facilities (Blue Sky Green Field Wind Energy Center (BSGF), Cedar Ridge Wind Farm (CR), and Forward Energy Wind Center (FE) in southeastern Wisconsin. These 3 energy developments are contained within 2 neighboring counties (Dodge and Fond du Lac) in similar land use and land cover, used similar post-construction study methodologies, have turbine models that are close in size and nameplate capacity, and all became operational within 7 months of each other. Analysis of these facilities as a group provides a detailed picture of regional fatalities. Therefore, our objectives were to combine bird and bat mortality across all 3 wind energy facilities:

1) To examine bird and bat species composition relative to mortality
2) To examine temporal and spatial patterns of bird and bat mortality;
3) To investigate whether select habitat, structural, and landscape features may influence mortality.

Bird mortality was low and within the norms observed by other studies; however, bat mortality was higher than most other previous research in Midwestern agricultural lands. Similarities within the data were shared by all 3 wind projects, including greater overall bat mortality at each wind facility relative to bird mortality, temporal and spatial patterns for bird and bat mortality, and avian species composition. Data differences across the 3 wind facilities included species composition of the bat mortalities and raw and corrected number of bat carcasses recovered. Our landscape analysis suggested that the fall season was the predictor variable that best explained bat mortality.

We recommend that pre- and post-construction bat monitoring occur at individual wind facilities rather than relying on published results from other wind facilities and assumptions that wind facilities in close geographic proximity will have similar mortality rates and species composition of mortalities. We also suggest further research be conducted to better understand and be able to predict bat mortalities, especially during peak mortality times in the fall, thereby refining curtailment as a cost-effective mitigation technique when necessary.

I. Introduction

Wind energy has been the fastest-growing renewable energy source for electricity in the United States. Wind energy production was 2,252 MW in 1999 and had increased to 34,296 MW by 2009 (U.S. Energy Information Administration). Of that total, 449MW of wind energy production is located in Wisconsin. Many states have renewable energy production standards requiring a certain percentage of energy production must be via renewable sources, so it is likely that construction of wind turbines will continue throughout the United States as well as in Wisconsin.

Wind turbines have been in operation in the United States since the early 1970s and have been considered an environmentally friendly method of electric generation. In the 1980s, however, large numbers of dead raptors were found in the vicinity of a large utility-scale wind turbine facility located at the Altamont Pass wind farm in California (Smallwood and Thelander 2008). Studies at other wind farms were conducted throughout the 1980s and 1990s to determine the extent of avian fatalities and species impacted (Kuvlesky et al. 2007).

Outside of California, studies found that different species of birds fatally collided with wind turbines, with songbirds being most vulnerable. Additional investigations found that certain factors appeared to influence the total number of birds killed at any given facility. These included avian abundance, species composition, geographic area, natural resources, prey availability, and turbine characteristics. This information provided the first steps in determining methods to minimize avian fatalities. Using monopole turbines instead of lattice turbines eliminated the avian nesting and perching opportunities on the turbine structures, which reduced fatalities. Conducting avian surveys and environmental assessments during the turbine siting process provided data on species abundance, local natural resources and avian habitat use. This information is used to determine the presence of endangered or threatened species, daily or seasonal migration corridors, or habitats that may be highly attractive to birds. There is a great deal of information regarding species abundance, habitat use and behavior which can be used for the macro-siting of wind farms as well as the micro-siting of individual turbines to minimize avian fatalities to the extent possible.

During an avian fatality study at the Buffalo Ridge Wind Farm in Minnesota in 2000, bat carcasses were unexpectedly discovered (Erickson et al 2001). Subsequent studies at Buffalo Ridge and other locations have indicated that bat fatality is a common occurrence at wind facilities. Initially, studies indicated that most fatalities consisted of tree roosting bat species (Kunz et al. 2007), but more recent studies have indicated that cave dwelling species may also be at risk (Grodsky 2010).

Relatively little is known about bat ecology. There is little information available about population numbers, migration patterns, hibernacula and maternity roosting locations on a national basis, and scant information on a regional or local basis may be available. While exact population numbers are unknown, population counts have been completed at some hibernacula, which provided a general indication of population for some species. Bats are known to have a long life span and slow reproductive rate. Loss of large numbers of bats may have significant impacts to local or regional populations. In addition to population loss through turbine fatalities, certain species may be additionally impacted by White Nose Syndrome. The recent discovery of White Nose Syndrome in New York State in the winter 2006-2007, caused by the fungus *Geomyces destructans*, has caused unanticipated decimation of cave dwelling bat species in the eastern portion of North America (Blehert et al. 2009).

Many studies have estimated avian and bat fatalities at wind turbine facilities (Kunz et al. 2007). Direct comparisons of the results of these studies is difficult and can be misleading due to the numerous differences in the study protocols and the methods used to develop a final estimate of fatality. These factors or biases include the following:

The number, type and size of wind turbines. A wind facility may consist of less than a dozen or up to hundreds of wind turbines. Turbines vary in size. Older turbine models are generally smaller. For example, hub height is 40 meters high with a rotor swept area of 1,400 square meters and an output of 0.66 MW. Newer turbine models generally have a hub height between 70 - 80 meters high, a rotor swept area of 4,000 – 5,000 square meters, and an output of 1.5-2.0 MW.

Variation in the overall size and composition of the search plot. Search plots that are too small may result in underrepresentation of avian fatalities, suggesting that search plots should be at least as long as the maximum blade tip height to encompass all potential fatalities (Johnson et al. 2003). Bat fatalities, on the other hand, tend to fall closer to the turbine relative to bird carcasses (Grodsky 2010, Kunz et al. 2007). Search plots in forested regions usually consist of the cleared area used for turbine construction (an irregular polygon). Plots in grasslands or croplands may consist of staggered mowed transects or square plots centered on the turbine.

Vegetative cover of the study area. Studies have been conducted in many habitat types, including forests, grasslands and croplands. Each cover type presents its own limitations in searcher success in finding carcasses. Vegetative cover can also change throughout the study field season, especially in croplands. Some, but not all studies, have included routine mowing of vegetation to increase the searcher efficiency.

Search interval. The interval varies among studies, from daily searches, weekly, biweekly and every 21 days (Smallwood 2007).

Methodologies for conducting the searcher efficiency trials and the predator carcass removal trials. Searcher efficiency and carcass removal trials are an integral part of correcting the bias inherent in developing an estimate of avian and bat fatality. However, mortality estimates can be different across studies due to the estimator used (Huso 2011), total number of trials completed during a single study, and the number and type of carcasses used, among other factors.

A number of researchers have identified differences like those above as a primary barrier to fully comparing results across wind energy studies and have stated the importance of regional studies with wind energy facilities that share commonalities in order to improve comparison of results across different sites and assist regulatory agencies in decision-making (Kunz et al.

2007, Kuvlesky et al. 2007, Arnett et al. 2008). We had a unique opportunity to compare the fatality estimates from 3 wind energy facilities in southeastern Wisconsin. The facilities are Blue Sky Green Field Wind Energy Center (BSGF), Cedar Ridge Wind Farm (CR), and Forward Energy Wind Center (FE). These 3 energy developments are contained within 2 neighboring counties (Dodge and Fond du Lac), used similar post-construction study methodologies and have turbine models that are close in size and nameplate capacity. Two of the 3 sites came on-line May, 2008, with the third becoming operational December, 2008 (Tables 1 and 2), and the study dates overlapped in time. Analysis of these facilities as a group provides a detailed picture of the fatalities in the region Therefore, our objectives were to combine bird and bat mortality across all three wind energy facilities:

1) To examine bird and bat species composition relative to mortality
2) To examine temporal and spatial patterns of bird and bat mortality;
3) To investigate whether select habitat, structural, and landscape features may influence mortality.

II. Study area

BSGF has 88 Vestas V-82 turbines capable of 1.65 MW output. The turbine hub is 80 m high, with a 41 m blade length, and a total height of 121 m at the tip of the blade. The rotor swept area is 5,281 m^2 (56,844 square feet). The project area is approximately 10,600 acres and is located in Fond du Lac County (Table 1).

CR consists of 41 Vestas V-82 turbines, which have the same dimensions as those used at BSGF as described above. This project area is approximately 7,808 acres and is located in southern Fond du Lac County (Table 1).

FE consists of 86 GE 1.5 MW turbines. The turbine hub is 80 m high, blade length is 38.5 m, and total height at the tip of the blade is 121 m. The rotor swept area is 5,346 m^2 (57,544 sq ft). The project area is located in southern Fond du Lac and Dodge Counties and encompasses 32,400 acres (Table 1).

Table 1. Characteristics of three wind facilities in southeastern Wisconsin.

	Blue Sky Green Field	**Cedar Ridge**	**Forward Energy**
Number of turbines	88	41	86
MW per turbine	1.65	1.65	1.5
Max. height of a turbine (ft.)	397	397	397
Size of wind farm (acres)	10,600	7,800	32,400
Primary land use	Agriculture	Agriculture	Agriculture
Operational start date	May, 2008	December, 2008	May, 2008

Land use in the area of each wind farm is primarily agricultural, consisting of corn, soybeans, small grains and alfalfa as well as dairy farming. The landscape is a patchwork of crop fields, pasturage, and rural homes. Woodlots, wetlands, and waterways are scattered throughout the area. In the northerly portion of the area is the City of Fond du Lac (population 42,203) and to the west is the City of Horicon (population 3,375) (2000 US Census). Smaller towns and villages are scattered throughout the project areas as well (Figure 1).

Figure 1. Location of Blue Sky Green Field (BSGF), Cedar Ridge (CR), and Forward Energy (FE) wind facilities plus select landscape features in southeastern Wisconsin.

There are significant habitat features in the region. The Horicon Marsh National Wildlife Refuge is located in Dodge County and is listed as a Wetland of National Importance. It is approximately 33,000 acres, and is one of the largest freshwater marshes in the United States. BSGF is 34 km northeast, CR is 26 km northeast, and FE is located approximately 7 km east of the Refuge. The southern portion of Lake Winnebago is located in north central Fond du Lac County. This lake has 137,708 surface acres and supports a large fishery including sturgeon. BSGF is located approximately 7 km east, CR is 12 km south, and FE is 21 km south of Lake Winnebago. Lake Michigan is east of the three sites, with BSGF, CR, and FE located 43, 48, and 63 km west, respectively (Figure 1).

Smaller permanent and vernal wetlands are found scattered throughout the 3 Project Areas, with communities typical of forest and scrub-shrub swamps, floodplain forests, deep and shallow marshes, and freshwater meadows. Non-native vegetation (e.g., spotted knapweed, Canada thistle, reed canary grass) can be found along roadways, ditches, and field edges.

Neda Mine State Natural Area (Neda Mine) is an abandoned iron mine and currently home to the largest known bat hibernaculum in the Midwestern United States. The hibernacula hosts an estimated 150,000 - 200,000 bats. The majority of these are little brown bats (*Myotis lucifugus*), although northern long-eared bats (*Myotis septentrionalis*), eastern pipistrelle bats (*Perimyotis subflavus*) and big brown bats (*Eptesicus fuscus*) are also found there. BSGF is 56 km northeast, CR is 38 km north, and FE is 22 km north of Neda Mine.

Kettle Moraine State Forest is a 52,000 acre area containing glacial hills, kettles, lakes, prairie, and mixed pine and hardwood forests. BSGF is 17 km west, CR is 13 km west, and FE is 22 km west of Kettle Moraine State Forest.

The Niagara Escarpment is the face of a 650-mile-long sickle-shaped bedrock ridge that runs from the northeastern United States, across portions of southeastern Canada, and then southward north and west of Lake Michigan to southeastern Wisconsin. In Wisconsin, the Niagara Escarpment extends for a distance of approximately 230 miles. In places throughout Wisconsin it is discontinuous, differing in elevation and amount of exposure. The escarpment abuts and parallels the shore of Lake Michigan and is between all three wind facilities and Lake Michigan.

III. Methods

Note: In the following sections, we refer to searcher efficiency, scavenger removal, and corrected mortality estimates. Searcher efficiency trials were conducted to determine how accurate each searcher was at locating carcasses within the defined search areas. To determine searcher efficiency, we placed a known number of bird or bat carcasses in defined search areas, unbeknownst to each searcher. Searcher efficiency is the total number of dead birds and bats located and tallied by a searcher relative to the actual number present. Scavenger removal trials allow us to understand how many carcasses were removed from a defined search area by a scavenger (i.e., raccoon, crow, etc.) prior to the searcher recovering the carcass. Once searcher efficiency and scavenger removal are known, they are entered into a calculation (a mortality estimator) that accounts for less than 100% searcher detection and removal of carcasses from the search area. The estimator provides an extrapolated value for bird and bat mortality.

Dates

We examined fatality data collected at BSGF and FE from July 15-October 31, 2008, fatality data collected at BSGF, CR, and FE April 15-May 31, 2009, and fatality data collected at CR and FE July 15-October 15, 2009. CR did not conduct fatality searches July 15-October 31, 2008, and BSGF did not conduct fatality searches July 15-October 15, 2009 (Table 2). Fatality searches were conducted at all 3 wind farms outside of the dates of this analysis, but the dates for which we conducted the analysis for this paper were the dates that overlapped amongst the 3 wind energy facilities.

Blue Sky Green Field

Search Plots and Searches

Thirty of the 88 turbines at BSGF were randomly selected and searched during the study. Plots were searched utilizing two separate methods. Both were defined by a square with sides 160 m long (25,600 m^2; 6.3 acres; 2.56 ha) centered on the turbine. At three randomly selected turbines, the entire search area was mowed and searched in its entirety. At the other 27 searched turbines, a total of six search transects were established, with each search transect measuring 160m long and 5m wide. Two strips were centered vertically on the turbine, orthogonal to each other, and the other four strips were placed horizontally at varying distances from the turbine. Half the turbines had these strips placed 10, 30, 50, and 70 m from the turbine, the other half had strips placed at 20, 40, 60, and 80 m from the turbine. This ensured that all distances from 0 to 80 m away from the turbine were sampled during searches. In addition, three randomly selected turbines (census plots) had the entire 160 m by 160 m search plot maintained in a low-growth vegetative condition.

Searches were conducted daily during the work week, with all 30 turbines searched at least once during the week. Ten of the 30 turbines were randomly assigned to be searched daily, and 20 turbines (five per day) were searched on a four to six day interval (Table 2). Searches typically began early each morning and continued until all 15 turbines had been searched that day.

Vegetation

Vegetation was mowed in all transects and search plots. For corn and small grain fields, a single mowing typically kept the area clear. Multiple mowing throughout the growing season was necessary for alfalfa fields and pastures.

Searcher Efficiency

A total of 172 carcasses were placed in the study area at different times and locations. Between 1 and 10 carcasses were placed on any single day. Searcher efficiency trials were conducted throughout the survey seasons. These carcasses were local bat species and a variety of local small bird and large bird species. All searcher efficiency trial carcasses were placed within the search plots being searched prior to the carcass search on the same day. The number of carcasses available for detection during each trial was determined immediately after the trial each day. Trial carcasses were retrieved and the number and location of found trial carcasses were documented after the regular searches each day.

Scavenger removal

Carcass removal trials were conducted during the period that carcass searches were conducted. Beginning August 18 and continuing through the end of the fall 2008 portion of the study, an average of 20 carcasses of either birds (two different size classes) or bats was placed in a search plot and monitored for up to 30 days. By spreading trials throughout the study period, the effects of varying weather, climatic conditions, and scavenger densities were taken into account. Two carcass removal trials were conducted in 2009; one on April 6 and one on April 27. Twenty carcasses of either birds (two different size classes) or bats were placed in a search plot and monitored for up to 30 days. Similar to the searcher efficiency trials, local native bird and bat species were used in the removal trials.

Corrected mortality estimates

The number of bird and bat carcasses found during scheduled searches, searcher efficiency, and scavenger removal rates were calculated to determine a corrected mortality estimate. For specific details regarding searcher efficiency and scavenger removal data and the calculator used, please refer to the BSGF final report “Post-Construction Bat and Bird Fatality Study at the Blue Sky Green Field Wind Energy Center, Fond du Lac County, Wisconsin” (Gruver et al. 2009; http://psc.wi.gov/apps35/ERF_view/viewdoc.aspx?docid=126370) on file with the Wisconsin Public Service Commission.

Table 2. Summary characteristics describing methods to assess bird and bat mortality at three wind energy facilities in southeastern Wisconsin.

	Blue Sky Green Field	**Cedar Ridge**	**Forward Energy**
Search dates	7/15 – 10/31, 2008 3/15 – 5/31, 2009	3/15 – 6/1, 2009 7/15 – 11/15, 2009	7/15 – 11/15, 2008 4/15 – 6/1, 2009 7/15 – 10/15, 2009
Search interval	10 turbines searched daily 20 turbines searched every 4-6 days	5 turbines searched daily 15 turbines searched every 4 days	10 turbines searched daily 10 turbines searched every 3 days 9 turbines searched every 5 days
% of total turbines searched	34	49	34
Size of total possible search area	160 m^2	160 m^2	160 m^2
Shape of total possible search area	square	square	square
# of search transects per total available search area	6	6	6
Dimension of each search transect	160m long by 5m wide	160m long by 5m wide	160m long by 5m wide

Cedar Ridge

Search Plots and Searches

Twenty of the 41 turbines in the project area were randomly selected and searched. Plots were searched utilizing two separate methods. All of the search plots consisted of 2.56-ha (6.3 ac) square plots having 160m long sides centered on the turbine. At two randomly selected turbines, plots were searched in their entirety ("census plots"); the remaining 18 turbines were sampled by searching 6, 6m wide transects. Two transects were centered on the turbine, perpendicular to each other. The other 4 transects intersected the plot at varying distances from the turbine. Transect centers were 10, 30, 50, and 70 m from the center of the turbine in half the plots, and 20, 40, 60, and 80 m from the turbine in remaining plots distances. The search area at each of the 18 sample plot turbines was approximately 0.558 ha (1.4 ac). Searching began in early morning and progressed continuously until completed by mid- to late-afternoon.

Of the 20 turbines, 15 were randomly selected and searched once every 4 days. The two census plots and three, randomly selected sample plots were surveyed daily (Table 2).

Vegetation

Vegetation was mowed in all transects and census plots. For corn and small grain fields, a single mowing typically kept the area clear. Multiple mowing throughout the growing season was necessary for alfalfa fields and pastures.

Searcher Efficiency

Searcher efficiency trials were conducted simultaneously with carcass searches. A total of 128 bird and bat searcher efficiency trial carcasses were placed during the spring and autumn migratory periods in 2009. In 2010 a total of 100 searcher efficiency trials were completed. Carcasses were placed at all 20 search plots, and no more than three carcasses were placed in a single search plot during one day. Following carcass searches, trial carcasses were retrieved and the number and location of found trial carcasses were documented. Carcasses used in trials consisted of non-native/non-protected or commercially available species and bird and bat carcasses salvaged from the project area. Bat carcasses were also obtained from the Wisconsin State Laboratory of Hygiene after being examined and cleared for rabies infection.

Scavenger removal

Scavenger removal trials were conducted during the spring and fall survey periods. Scavenger removal trials were conducted separately from searcher efficiency trials to avoid placing too many carcasses in one area. Bird carcasses of various sizes and bat carcasses were placed at all 20 search plots, marked with an inconspicuous plastic plant stake, and no more than two carcasses were placed in a single search plot during a survey period. The observer conducting the carcass searches surveyed the carcasses over a period of 30 days. Carcasses were checked daily for the first five days, every three days between days 6 and 20, and on day 30. Remaining trial carcasses were removed at the end of 30 days. A total of 116 bird and bat carcasses were placed for scavenger removal trials during the 2009 spring and fall migratory periods. In 2010 a total of 100 bird and bat scavenger removal trials were conducted.

Corrected mortality estimates

The number of bird and bat carcasses found during scheduled searches, searcher efficiency, and scavenger removal rates were calculated to determine a corrected mortality estimate. For specific details regarding searcher efficiency and scavenger removal data and the calculator used, please refer to the CR final report "Post-Construction Bird and Bat Mortality Study, Cedar Ridge Wind Farm, Fond du Lac County, Wisconsin" (BHE Environmental 2011; http://psc.wi.gov/apps35/ERF_view/viewdoc.aspx?docid=146174) on file with the Wisconsin Public Service Commission.

Forward Energy

Search Plots and Searches

Of the 86 turbines, 29 were randomly selected and searched for bird and bat carcasses. The FE was divided into 3 north-south oriented sections (strata), each approximately 3.22 km wide, which allowed establishment of an impact gradient as distance increased eastward from Horicon Marsh and northward from Neda Mine. Number of selected turbines in each section was proportional to the total number of turbines in each section. Because the western, central, and eastern strata contained 48%, 38%, and 14% of the total number of turbines at the wind energy facility, respectively, 14, 11, and 4 turbines were searched within each respective section.

An area measuring 160 by 160 meters (6.3 acres), with the turbine at the center, was defined for each of the 29 turbines. Three, randomly selected turbines (1 in each north-south section) had the entire available search area cleared and were searched either every 1, 3, or 5 days. To minimize impacts on crops and landowners, 26 of the 29 searched turbines had 19% (1.2 acres) of the total searchable area monitored, using 5, parallel 160 m by 5 m transects. The transects were selected randomly from a grid of 4.6 m by 4.6 m squares superimposed upon the total searchable area (Fig. 3). The 5 parallel transects were perpendicular to the turbine access road. The access road itself plus an extension and the pad of the turbine served as a sixth search transect.

Turbines were randomly selected to be searched every 1, 3, and 5 days (Table 2). In 2009, three control sites were established outside the study site and each was randomly selected to be searched at 1, 3, and 5 days. The control sites were designed to estimate the likelihood of birds and bats being killed in the study area by causes independent of the wind turbines. Each control site mimicked search areas inside the study site and searchable area equaled 1.2 acres. Carcass searches commenced 30 minutes prior to sunrise to reduce the potential that a carcass was removed by daytime scavengers and concluded by 1200 hrs. at the latest. Searchers were randomly assigned to turbines and then searched those same turbines throughout the season, including the three fully cleared plots.

Vegetation

The search areas were mowed regularly throughout the course of the mortality searches.

Searcher Efficiency

Searcher efficiency trials were conducted throughout the research period. One-hundred bird and 100 bat carcasses were put out within the 26 search areas for fall and spring seasons, 2008 and

2009. Roughly one bird and one bat were placed at a randomly selected turbine each search day. This was repeated for all 26 turbines. Placement and timing of the carcasses were not known to searchers, and a searcher efficiency rate was calculated for each searcher at the end of the fall and spring search seasons. All placed carcasses were marked, recorded by location, and removed at the end of the trial.

Scavenger removal

Scavenger removal trials followed the same pattern as for searcher efficiency trials, using 100 bird and 100 bat carcasses placed at the same rate as for searcher efficiency trials among the 26 turbines. In 2009, mouse (*Mus* genus) carcasses were used as surrogates for bat carcasses in scavenger removal trials because there were insufficient bat carcasses. Approximately half of the 100 weanling (20-25 days old) mice were grey in color and half were black in color to simulate the pelage of commonly killed bat species. The use of surrogate mice enabled all found bat carcasses to be necropsied, which allowed for better species and sex identification as well as verification of the cause of death. Carcasses were checked once every 24 hour period to note presence/absence in order to identify how long after placement until a scavenger found it. All placed carcasses were recorded by location and removed at the end of the search interval for that specific turbine (i.e. at the end of 1, 3, or 5 days).

Corrected mortality estimates

The number of bird and bat carcasses found during scheduled searches, searcher efficiency, and scavenger removal rates were calculated to determine a corrected mortality estimate. For specific details regarding searcher efficiency and scavenger removal data and the calculator used, please refer to the FE final report “Assessing Bird and Bat Mortality at the Forward Energy Center” (Grodsky and Drake 2011; http://psc.wi.gov/apps35/ERF_view/viewdoc.aspx?docid=152052) on file with the Wisconsin Public Service Commission.

Landscape features relative to bird and bat mortality

For the landscape level analysis, we examined only bat mortality relative to select structural, habitat, and landscape features at both a fine and broad spatial scale. We were not able to examine bird mortality because of lack of data. At both scales, we examined bat mortality relative to select features at each individual turbine where mortality searches occurred per wind facility. Because the spring and fall seasons were of varying length, and each wind facility used different search intervals (i.e., 1, 3, and 5 days), we standardized bat mortality by number of days searched. We used observed (i.e., non-corrected) mortality data because numbers of carcasses set out at individual turbines to monitor searcher efficiency and scavenger removal were too few to calculate a robust corrected mortality estimate.

We located turbines using aerial photographs in Google Earth and used the distance tool to measure nearest distance to select features. Height of aerial photographs varied between 939 – 1113 feet. Dates of the aerial photographs used were 2008 for Blue Sky Green Field and Cedar Ridge and 2011 for Forward Energy. Individual turbines were clearly visible for the BSGF and FE sites, but only the turbine pad and access roads were visible for CR because the turbines had not yet been constructed. We used the latitude and longitude coordinates for each turbine to verify location for CR.

At a fine scale, we measured distance (in m) from the base of each searched turbine to nearest edge of building, turbine base, wooded habitat, wetland area, and paved road. For each wind facility, we excluded data from turbines with census plots for ease of comparison. Examples of buildings included houses, barns, or other out buildings. If more than 1 wooded or wetland habitat was in close proximity to a turbine, we chose the largest wooded or wetland habitat. We defined wetland areas as those with standing water that could be seen from aerial photography at the time the photographs were taken.

At a broad scale, we measured distance (in km) from the base of each searched turbine to nearest boundary of Lakes Winnebago and Michigan, the Refuge, Neda Mine, Kettle Moraine State Forest, and the Niagara Escarpment. For each wind facility at both landscape scales, we excluded data from turbines with census plots for ease of comparison.

All statistics for the spatial scale-specific analysis were conducted using R software (version 2.11.1; R Foundation for Statistical Computing, Vienna, Austria). We evaluated 6 linear mixed effects models using the "lme4" package, which allowed for fixed and random effects (Table 8). The response variable for each model was total bat mortality per searched turbine per number of days searched. We evaluated predictor variables for co-linearity using Pearson's correlation matrix. When we encountered correlated variables, we randomly excluded one from further consideration in our models. The fixed effect predictor variables for the fine scale models were windfarm (BSGF, CR, or FE), season (fall, spring), and distance to the nearest building (nearbldg), nearest road (nearroad), nearest woodland (nearwood), nearest wetland (nearwet), and nearest turbine (nearturb). The fixed effect predictor variables for the broad scale models were windfarm (BSGF, CR, or FE), season (fall, spring), and distance to Lake Michigan (lmich), Lake Winnebago (lwinn), and Kettle Moraine State Forest (kmsf). The last set of models we evaluated combined all above fixed effect variables at both the fine and broad scale. For all models the random effect predictor variable was searched turbine per wind facility. At the fine, broad, and fine and broad combined scales, we examined each model using a negative binomial and Poisson regression, and determined the best fitting model according to AIC_c, ΔAIC_c, and AIC_c weights. We designated individual predictor variables in the best fitting model as significant if $P < 0.05$.

IV. Results

Overall non-corrected carcass numbers

The greatest raw number of total bat and bird carcasses were found at BSGF (N = 234). Combined bird and bat carcass finds at CR (N = 117) was 50% less and FE (FE; N = 140) discovered about 40% fewer carcasses as found at BSGF. Bat carcasses found at BSGF (n = 194) was more than twice what was found at CR (n = 84) and 38% greater than at FE (n = 121). BSGF (n = 40) and CR (n = 33) experienced relatively equal bird fatality, and greater than FE (n = 19) (Table 3). The non-corrected carcass totals reported above do not account for searcher efficiency and scavenger removal rates, nor do they include mortality as a result of "incidental finds". Carcasses found at a turbine that was not one of the study turbines, or at a study turbine outside of the search period, were considered "incidental finds". The number of incidental finds varies greatly among studies and some studies do not count incidental finds at all. Typically, incidental finds are not included in the corrected mortality estimate due to this variability.

Table 3. Bird and bat mortality at 3 wind energy facilities in southeastern Wisconsin, 2008-2009.

Wind Energy Facility	**Dates**	**# of bat fatalities**	**# of bird fatalities**
Blue Sky Green Field	Fall 2008	190	30
	Spring 2009	4	18
Cedar Ridge	Fall 2009	77	15
	Spring 2009	7	13
Forward Energy	Fall 2008	77	6
	Spring 2009	3	12
	Fall 2009	41	1

Bat fatality

Of the 7 bat species that inhabited the area where the 3 wind farms are located, carcasses of at least 5 bat species were recorded at all 3 wind farms. Carcasses of unidentified bats and unidentified *Myotis* species were recovered at BSGF and FE. Silver haired (n = 103), hoary (n = 92), and little brown (n = 84) bats were the most common bat species found when examining combined fatality at all 3 wind farms, followed by big brown (n = 72) and eastern red (n = 45) bats. No eastern pipistrelle or northern myotis bats were found as fatalities at any of the wind farms included in this study (Table 4).

Species differences existed across the individual wind facilities. Of the 194 bat carcasses recovered at BSGF, little brown (n = 60, 31%) and silver haired (n = 51, 26%) bats accounted for more than half of the found bat carcasses. Of the 84 bat carcasses found at CR, hoary bats (n = 29, 35%) were found approximately twice as often as other recovered species. At FE, silver haired (n = 36, 29%) and hoary (n = 34, 28%) bats accounted for more than half of all bat carcasses found, and those 2 species were found at least twice as often as other bat species (Table 4). Within Wisconsin, the big brown, eastern pipistrelle, little brown, and northern myotis bats are state threatened species, and the hoary, eastern red, silver-haired bats are species of conservation need.

Table 4. Species composition of bat mortality at 3 wind energy facilities in southeastern Wisconsin, 2008-2009.

	Wind Energy Facility		
Bat Species	**Blue Sky Green Field N (%)**	**Cedar Ridge N (%)**	**Forward Energy N (%)**
Big Brown Bat* (*Eptesicus fuscus*)	33 (17)	15 (18)	11 (9)
Eastern Pipistrelle* (*Pipistreelus subflavus*)	0	0	0
Little Brown Bat* (*Myotis lucifugus*)	60 (31)	12 (14)	12 (10)
Northern Myotis* (*Myotis septentrionalis*)	0	0	0
Hoary Bat** (*Lasiurus cinereus*)	29 (15)	29 (35)	34 (28)
Eastern Red Bat** (*Lasiurus borealis*)	11 (6)	12 (14)	14 (12)
Silver-haired Bat** (*Lasionycteris noctivagans*)	51 (26)	16 (19)	36 (29)
Unidentified Species	10 (5)	0	14 (12)

*Wisconsin state threatened species

**Wisconsin species of conservation need

Bird fatality

At least 32 bird species were represented across all 3 wind farms, not including unidentified meadowlark, sparrow, and swallow species, as well as a general category termed "unidentified bird". A combined total of 92 bird carcasses were recovered during fatality searches across the 3 wind farms. BSGF (n = 40) and CR (n = 33) found more bird carcasses than were found at FE (n = 19). Only 3 identified bird species (Ruby-crowned Kinglet, Savannah Sparrow, and Tree Swallow) were mortalities common to all 3 wind farms. Of the species positively identified, the

Tree Swallow (n=8), Golden-crowned (n=6) and Ruby-crowned Kinglets (n=6) were the species with the highest individual mortality (Table 5). No federal endangered or threatened bird species were found as mortalities at any of the wind farms in this study. However, 6 bird species defined by the State of Wisconsin as species of special concern were recovered during mortality searches. They were the Black-billed Cuckoo (*Coccyzus erythropthalmus*), Bobolink (*Dolichonyx oryzivorous*), Eastern Meadowlark (*Sturnella magna*), Purple Martin (*Progne subis*), Ruby-crowned Kinglet (*Regulus calendula*) and Yellow-bellied Flycatcher (*Empidonax flaviventris*) (Table 5).

Table 5. Species composition of bird mortality at 3 wind energy facilities in southeastern Wisconsin, 2008-2009.

	Wind Energy Facility†		
Bird Species	**Blue Sky Green Field**	**Cedar Ridge**	**Forward Energy**
American Goldfinch (*Carduelis tristis*)	0	1	0
American Redstart (*Setophaga ruticilla*)	0	0	1
Barn Swallow (*Hirundo rustica*)	0	1	1
Black and White Warbler (*Mniotilta varia*)	0	0	2
Black-billed Cuckoo* (*Coccyzus erythropthalmus*)	0	0	1*
Blackpoll Warbler (*Dendroica striata*)	0	0	1
Black-throated Green Warbler (*Dendroica virens*)	1	0	0
Bobolink* (*Dolichonyx oryzivorus*)	0	0	1*
Brown Creeper (*Certhia Americana*)	0	1	0
Brown-headed Cowbird (*Molothrus ater*)	2	0	0
Cedar Waxwing (*Bombycilla cedrorum*)	1	1	0
Cliff Swallow (*Hirundo pyrrhonota*)	0	1	1
Dark-eyed Junco (*Junco hyemalis*)	0	1	0
Eastern Meadowlark* (*Sturnella magna*)	1	0	0
European Starling (*Sturnus vulgaris*)	1	0	1
Golden-crowned Kinglet (*Regulus satrapa*)	4	2	0
Horned Lark (*Eremophila alpestris*)	3	0	0

Killdeer (*Charadrius vociferus*)	0	0	1
Magnolia Warbler (*Dendroica magnolia*)	0	2	0
Mourning Dove (*Zenaida macroura*)	0	2	0
Purple Martin* (*Progne subis*)	0	1	0
Red-eyed Vireo (*Vireo olivaceus*)	0	0	2
Red-tailed Hawk (*Buteo jamaicensis*)	0	2	2
Red-winged Blackbird (*Agelaius phoeniceus*)	0	1	0
Rock Dove (*Columba livia*)	0	3	0
Ruby-crowned Kinglet* (*Regulus calendula*)	2	2	2*
Savannah Sparrow (*Passerculus sandwichensis*)	1	1	1
Tree Swallow (*Tachycineta bicolor*)	2	4	2
Warbling Vireo (*Vireo gilvus*)	1	0	0
Wild Turkey (*Meleagris gallopavo*)	0	1	0
Yellow-bellied Flycatcher* (*Empidonax flaviventris*)	0	1	0
Unidentified Bird	21	5	0

[†] Numbers in each column represent number of individuals of that species found during mortality searches.
*Wisconsin species of special concern

Temporal Patterns

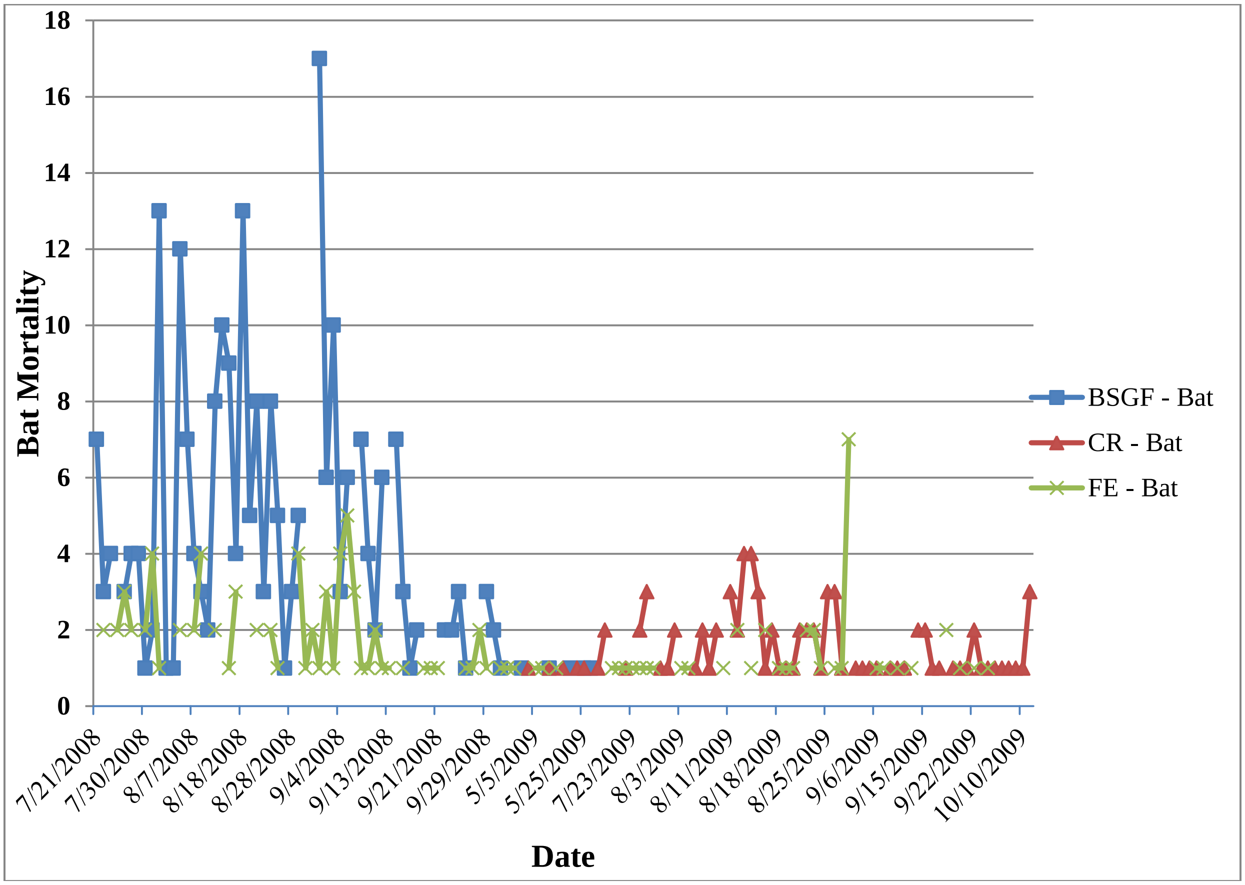
Bat fatality

The overwhelming majority of bat mortality at the 3 wind farms was during fall relative to spring. Depending on the wind farm, between 93% and 98% of all bat mortality occurred during the fall (Table 3). Bat fatality during the Fall 2008 field season peaked at BSGF at the end of July and into the first week of August, peaked again starting at the end of the second week and into the third week of August, and then peaked again the first 2 weeks of September. The largest peak occurred September 1 with 11 bats found (Figure 2). During that same field season, bat fatality at FE peaked at the end of July, the beginning of the second week of August, and then the end of August and into the first 2 weeks of September. The largest peak during the Fall 2008 season at FE was on September 5 when 5 bats were recovered (Figure 2).

Bat fatality during the Fall 2009 field season at CR showed a small peak at the end of July, and the second and fourth weeks of August, with the largest peak occurring on August 13 and 14 (4 bats recovered each day) (Figure 2). Bat fatality at FE demonstrated only one peak on August 28. The August 28 peak (7 bats) was the largest peak of either the 2008 or 2009 fall field season at FE (Figure 2).

Bat fatality for Spring 2009 showed no peaks (Figure 2). No more than 1 bat per day was ever found at any of the wind farms. Fourteen bat carcasses across all 3 wind farms were found throughout the Spring 2009 field season. The first carcass was retrieved April 30, and then carcasses were found at a relatively regular interval throughout May.

Figure 2. Temporal patterns of bat mortality at 3 wind energy facilities in southeastern Wisconsin, 2008-2009.



Of 109 searchable days during the Fall 2008 field season, 59 (54%) days occurred when no bats were found during carcass searches at BSGF (22 consecutive days was the longest period without finding a bat carcass; Oct. 2-23) and 68 (62%) days passed where no bat carcasses were retrieved at FE (19 consecutive days was the longest period without finding a bat carcass; October 13 – October 31).

There were 47 searchable days during the Spring 2009 field season, and no bats were found at BSGF 44 (92%) of those days (24 consecutive days was the longest period without finding a bat carcass; April 15-May 7). At CR, 42 (88%) days occurred where no bat carcasses were found (15 consecutive days was the longest period without finding a bat carcass; April 15 – April 29), and 45 (94%) days occurred where not bats were found at FE (21 consecutive days was the longest period without finding a bat carcass; April 15 – May 4).

Of 93 searchable days during the Fall 2009 field season, no bats were found at CR 42 (45%) of those days (6 consecutive days was the longest time span without finding a bat carcass; September 29 – October 4). At FE, bats were not found 68% (63 days) of the time. Twenty-one days (September 25 – October15) was the longest period in Fall 2009 between bat mortalities.

Bird fatality

Bird fatality was less than bat fatality at each of the 3 wind farms in all seasons and all years (Table 3). The greatest single day peak in bird fatality in any season or year was 3 birds. Bird fatality during the Fall 2008 field season at BSGF displayed single peaks (of two birds each) on August 5, September 10, and October 14 and 20. Bird fatality during the Fall 2008 field season at FE displayed a single peak on August 21.

Bird fatality during the Fall 2009 field season at CR showed peaks on July 14, August 13, and September 23. FE experienced only one bird mortality during the Fall 2009 field season.

Bird fatality for Spring 2009 showed 3 single peaks. Two peaks of 2 mortalities per day were discovered at CR on April 18 and April 30. FE experienced a 2 bird fatality peak on April 29. Otherwise, single bird mortalities were spread out across the Spring 2009 field season.

Spatial Patterns

Bat fatality

At least 1 bat carcass was found at each of the 30 turbines at BSGF. Of the 10 turbines that were searched daily, 19 carcasses were recorded at one turbine, 16 carcasses were recorded at a second turbine, and 13 bat carcasses were found at 2 different turbines (one of which was a census turbine where the entire 6.3 acres were searched). Of the 20 turbines searched every 4-6 days, the most bat carcasses recorded at a single turbine was 13. Eleven bats were found at a second turbine. Regardless of the search interval, no more than 10 bat carcasses were found at 77% (n=23) of the turbines. Slightly more bat fatalities were found in the northern portion of the study area (54.2%) than were found at the southern portion (45.7%).

Two turbines at CR recorded no bat carcasses throughout the duration of the fatality study. Two of the 3 turbines where the greatest numbers of bats (13 and 11 carcasses) were found were census turbines. Of the turbines that were searched daily, 5-7 bat carcasses were found at each of the 3 turbines. Of the 15 turbines where the search interval was 4 days, 11 carcasses were retrieved at one turbine, 7 at a second turbine, and 5 at a third turbine. Four or fewer bat carcasses were found at 60% (n=12) of all searched turbines. There was no noticeable pattern regarding fatality per turbine as the 4 turbines with the highest recorded fatalities were scattered in the north, south, and east sections of CR.

At least 1 bat carcass was found at every searched turbine at FE. One of the turbines containing a census plot recorded the greatest number of bat carcasses (n = 15) of all turbines searched. The other 2 turbines that had census plots recorded 6 and 3 bat carcasses. Of the turbines searched daily, 13 bat carcasses were found at one turbine and 10 bats were found at another turbine. All other turbines searched daily recorded 1-10 bat carcasses, and turbines searched every 3-5 days recorded 1–5 bat carcasses. Four or fewer bats carcasses were found at 62% (n = 18) of all searched turbines. Bat fatality was recorded in all three study sections at FE, with 33%, 44%, and 23% of the total bat fatality recorded in the western, central, and eastern sections, respectively. Bat fatality was relatively evenly distributed throughout the wind farm, although the 5 turbines that recorded the highest fatality were situated in the eastern half of the wind facility.

Bird fatality

No bird carcasses were found at 8 turbines at BSGF. The greatest number of bird carcasses found at a single turbine was 8, and that turbine was searched daily. Other than 3 turbines recording between 3 and 4 bird carcasses, 56% of turbines where at least 1 carcass was found (n = 18) recorded ≤ 2 bird carcasses. Only one turbine (B20) at BSGF recorded both high numbers of bat and bird carcasses.

No bird carcasses were found at 2 turbines searched at CR. One of the 2 turbines containing census plots recorded the highest number of retrieved bird carcasses (n = 7). Of the non-census plot turbines 3-5 bird carcasses were recorded at 4 turbines. The remainder of the turbines at CR recorded ≤ 2 birds. Four or fewer bird carcasses were found at 18 (90%) of all searched turbines.

No bird carcasses were found at 16 searched turbines at FE. The greatest number of bird carcasses (n = 5) were found at one of the census plots. Two birds were found at turbine 107. Turbines where search plots were sampled resulted in 3 birds at one turbine and 2 birds at a second turbine. All other searched turbines where birds were found resulted in single carcasses. Turbines searched daily resulted in 0-3 bird carcasses. The number of birds found at turbines searched every 3 and 5 days was 0-1 birds.

Corrected mortality estimates

Mean estimated mortality for BSGF for Fall 2008 was 0.35 bats/turbine/day (SE = 0.05) and 0.11 birds/turbine/day (SE = 0.03). For Spring 2009, mean estimated mortality was 0.02 bats/turbine/day (SE = 0.01) and 0.02 birds/turbine/day (SE = 0.02) (Tables 6 and 7). For the

Fall 2008 season, total estimated mortality at all 88 turbines for BSGF for bats was 3,453 and 959 birds. Total estimated mortality for Spring 2009 was 83 bats and 83 birds.

Mean estimated mortality for CR for Fall 2009 was 0.44 bats/turbine/day (SE = 0.1) and 0.03 birds/turbine/day (SE = 0.01). For Spring 2009, mean estimated mortality was 0.18 bats/turbine/day (SE = 0.1) and 0.05 birds/turbine/day (SE = 0.02) (Tables 6 and 7). For the Fall 2009 season, total estimated mortality at all 41 turbines for CR for bats was 1,685 and 130 birds. Total estimated mortality for Spring 2009 for bats was 339 and 87 birds.

Mean estimated mortality for FE for Fall 2008 was 0.27 bats/turbine/day (SE = 0.03) and 0.03 birds/turbine/day (SE = 0.01). For Spring 2009, mean estimated mortality was 0.02 bats/turbine/day (SE = 0.02) and 0.07 birds/turbine/day (SE = 0.02). For Fall 2009, mean estimated mortality was 0.21 bats/turbine/day (SE = 0.04) and 0.004 birds/turbine/day (SE = 0.004) (Tables 6 and 7). For the Fall 2008 season, total estimated mortality at all 86 turbines for FE for bats was 2,540 and 235 birds. Total estimated mortality for Spring 2009 for bats was 86 and 281 birds, and 1,672 bats and 30 birds for Fall 2009.

Table 6. Corrected bat mortality estimates for 3 wind energy facilities in southeastern Wisconsin, 2008-2009.

Wind Energy Facility	**Dates**	**Mean # bat mortalities (turbine/day)**	**SE**
Blue Sky Green Field	Fall 2008	0.35	0.05
	Spring 2009	0.02	0.01
Cedar Ridge	Fall 2009	0.44	0.01
	Spring 2009	0.18	0.01
Forward Energy	Fall 2008	0.27	0.03
	Spring 2009	0.02	0.02
	Fall 2009	0.21	0.04

Table 7. Corrected bird mortality estimates for 3 wind energy facilities in southeastern Wisconsin, 2008-2009.

Wind Energy Facility	**Dates**	**Mean # bird mortalities (turbine/day)**	**SE**
Blue Sky Green Field	Fall 2008	0.11	0.03
	Spring 2009	0.02	0.02
Cedar Ridge	Fall 2009	0.03	0.01
	Spring 2009	0.05	0.02
Forward Energy	Fall 2008	0.03	0.01
	Spring 2009	0.07	0.02
	Fall 2009	0.004	0.004

Landscape Analysis

The broad scale Poisson regression model was the best fitting model of the 6 we evaluated, according to the various AIC_c criteria (Table 8). There was also some support for the broad scale negative binomial regression model ($\Delta\ AIC_c = 2.37$). Of the predictor variables included in the Poisson broad scale model, only season ($P < 0.001$) was significantly associated with bat mortality (Table 9).

Table 8. Best fitting model, AIC_c and P values for bat mortality relative to select structural and habitat features in southeastern Wisconsin, 2008-2009.

Regression Model	**Predictor variables***	**AIC_c**	**$\Delta\ AIC_c$**	**$AIC_c\ w_i$**
Negative binomial fine scale	nearbldg + nearwoods + nearwet + nearroad + nearturb + windfarm + season + turbine	32.97	7.4	0.01
Poisson fine scale	Same as above	30.57	5	0.06
Negative binomial broad scale	lmich + lwinn + kmsf + windfarm + season + turbine	27.94	2.37	0.22
Poisson broad scale	Same as above	25.57	0	0.71
Negative binomial fine + broad scale	nearbldg + nearwoods + nearwet + nearroad + nearturb + lmich + lwinn + kmsf + windfarm + season + turbine	40.47	14.9	0
Poisson fine + broad scale	Same as above	38.12	12.55	0

*Turbine was a random effect. All others were fixed effects.

Table 9. Evaluation of fixed effects associated with bat mortality at 3 wind facilities in southeastern Wisconsin, 2008-2009.

Predictor variable	***P* value**
Lake Michigan	0.56
Lake Winnebago	0.26
Kettle Moraine State Forest	0.44
Season	0.001
Windfarm	0.31

V. Discussion

Kunz et al. (2007) stated the importance of quantifying geographic patterns of bat activity and migration relative to topography and land cover when examining impacts to bats from wind energy. A number of other researchers have suggested that results from previous wildlife-wind farm studies cannot be compared because methodologies and data collection were unique to each study (Piorkowski et al. 2012). The uniqueness of our study is that we were able to compare bird and bat mortality across 3 separate wind energy facilities that were located in 2 neighboring counties in the southeastern quadrant of Wisconsin. Each of the 3 wind projects shared many similarities in terms of turbine characteristics, (i.e., height and MW output), number of turbines (although CR had 41 turbines, BSGF and FE each had 88 turbines), and all 3 projects came on-line within 7 months of one another. Additional similarities included nearly identical search methodologies and comparable topography, land uses and land covers, with each project sited in predominantly agricultural areas.

Similarities within the data were shared by all 3 wind projects. We found greater overall bat mortality at each wind facility relative to bird mortality, which is a common theme at most wind farms (Barclay et al. 2007). Baerwald et al. (2008) suggested bats experienced greater turbine-caused mortality than birds due to barotrauma. Barotrauma occurs when a bat moves through the drop in atmospheric pressure that is created by moving turbine blades. Due to differences in physiology and anatomy, bats seem more susceptible to barotrauma than birds (Grodsky et al. 2011). Grodsky et al. (2011) confirmed that bats die from barotrauma and indicated that it is not the dominant cause of turbine-caused bat mortality, but instead is a contributing cause along with blunt force trauma. Although the exact cause of mortality is becoming better understood, the reason why bats cannot avoid wind turbines given their sensory systems is still not known.

A second similarity in the data amongst all 3 wind facilities and a theme common to other studies is the species composition of bat and bird fatalities. Studies have found that migratory, tree roosting bats (eastern red, silver haired, and hoary bats) are the most common species collected during mortality searches at wind facilities (Kuvlesky et al. 2007, Arnett et al. 2008, Baerwald and Barclay 2011). Other species commonly found at wind facilities but in smaller numbers include big and little brown bats (Kunz et al. 2007). When examining bat mortality across all 3 wind projects, 2 of the 3 tree roosting species (silver-haired and hoary bats) were the most common bat species killed, with little brown bats being the third most common species. However, when examining species composition at individual facilities, migratory, tree roosting bats were the most common species at CR and FE, but little brown bats were the most commonly found species at BSGF. At all 3 wind facilities, the big brown bat was strongly represented as well. The fact that little brown and big brown bats were frequent mortalities is a finding not generally reported in the literature, and both of these species are susceptible to White-nose Syndrome.

One hypothesis that may explain why migratory, tree roosting bats, in particular, are found in comparatively larger numbers as fatalities is that they roost in trees during the day, and as they seek shelter as daylight approaches, may mistake turbine monopoles for roost trees (Kunz et al. 2007). A second idea is that all types of bats may be attracted to turbines due to sounds produced by turbines or modifications to the landscape during the installation of a wind facility that creates suitable habitat (Kunz et al. 2007). Alternatively, as bats come in close proximity to turbines, they may become acoustically disoriented or trapped within the vortex created by the spinning turbine blades (Horn et al. 2008).

Nocturnally migrating passerines have been the most common avian species recovered during fatality searches at wind energy facilities (Kuvlesky et al. 2007). Avian mortalities recorded at our 3 wind facilities consisted primarily of nocturnally migratory birds, many of which were passerines. A number of factors have been proposed explaining why nocturnal migrants seem most susceptible to turbine-related mortality relative to other bird species, including location of turbines in areas where birds are known to inhabit, specific features of a wind facility (i.e., turbine layout, height, and lighting), and weather variables (Kuvlesky et al. 2007).

Temporal patterns of bat mortality at the 3 wind facilities we studied were similar to what has been reported in the literature. Bat mortality was consistently greater during fall versus spring search seasons, and peaked between late July and mid-September, with the greatest peak occurring between mid-August and the first week of September, depending on the wind facility. It has been suggested that bat mortality is greatest during fall because there are a greater number of individual bats in the environment following the spring and summer reproductive periods, the juvenile bats are inexperienced flyers, and the fall migration season is much longer then the spring migration period (Arnett et al. 2008, Baerwald and Barclay 2011).

In addition to peaks in mortality, we experienced periods when no bats were discovered. During fall field seasons, no bat carcasses were found between 45-68% of the searchable days, and long periods of time elapsed (up to 22 days) between bat fatalities. Most of the time (≥ 88%) during the spring field season no bat carcasses were found. Horn et al. (2008) reported large variations in bat activity at a wind facility and attributed it to variations in insect activity. We disagree with Horn et al. (2008) because it is unlikely that insects were absent in and around turbines for long periods of time (i.e., 22 days), although we have no evidence to support our hypothesis as we did not collect data on insect activity. Furthermore, a complementary study at FE using ultrasonic recorders to monitor bat activity conducted simultaneously with mortality searches consistently recorded bats during times when no bats where found during mortality searches (Mike Watt, personal communication 2011). Therefore, we’re confident bats were present at FE although none were recovered at times during mortality searches.

Bird mortality at the 3 wind facilities did not exhibit a strong temporal pattern, which is consistent with the literature (Kuvlesky et al. 2007). We did not conduct mortality searches outside of the fall and spring avian migratory periods. However, both CR and FE conducted late fall (October 15-November 15) searches and no bird carcasses were found, suggesting that avian mortality in our area of study may be concentrated during times of migratory activity.

Spatially, we found no distinct patterns amongst any of the 3 wind farms regarding bat mortality. With rare exception, at least one bat carcass was found at nearly every searched turbine. Bat mortality was relatively evenly distributed across each of the 3 wind farms. Bird mortality was also relatively evenly distributed across each wind farm, but a greater number of turbines at BSGF and FE recorded no bird mortality, most likely a result of fewer total birds killed at each wind facility relative to bats.

Converting our corrected mortality estimates from number of bat mortalities/turbine/day to number of mortalities/turbine/entire study for each of our 3 wind facilities for ease of comparison with other studies, the corrected bat mortality estimate ranged across our 3 wind projects from 21 bats/turbine (FE) to 49 bats/turbine (CR). Our corrected estimates are higher than what has been typically reported for wind facilities in the midwestern United States, and rival the corrected estimates for wind projects operating on wooded ridge tops in the eastern United States (Arnett et al. 2008). Estimated mean bat fatality/turbine in the midwestern United States has ranged from 0.1 to 7.8 (Arnett et al. 2008). Estimated mean bat fatality/turbine in the eastern United States has ranged from 20.8 to 69.6 (Arnett et al. 2008). The number, type, and size of turbines varied amongst the reported mortality estimates in Arnett et al. (2008), as did the length of each study, making direct comparison between our results and other reported results difficult. However, all of the wind facilities reporting mortality estimates from the midwestern United States were situated in habitats similar to where our wind facilities were constructed. The majority of the wind projects in the eastern United States were constructed on wooded ridge tops.

Corrected bird mortality estimates across our 3 wind farms ranged from 5.02 birds/turbine (CR) to 11.22 birds/turbine (BSGF). The limited studies that have reported bird mortality estimates for wind projects in the midwestern United States ranged from <1 bird/turbine to 2.83 birds/turbine (Erickson et al. 2001, Kuvlesky et al. 2007). Throughout the United States, bird mortality estimates have ranged from 0 to 4.45 birds/turbine (Kuvlesky et al. 2007). As with comparing bat mortality estimates, it is difficult to draw direct comparisons between our 3 wind facilities and other wind projects due to the same causes of variability.

Landscape Analysis

We did not examine select weather variables while trying to explain bat mortality at any of the 3 wind facilities because we collected weather data for all 3 wind facilities from the same weather station at the Fond du Lac, WI airport. Furthermore, while each wind facility collected assorted weather data at their facility and at each individual turbine, those data were unavailable. Because of the limitation with the weather data, we instead focused on structural, habitat, and landscape features to try and understand regional bat mortality.

Season was the only significant predictor variable associated with bat mortality. The majority (96%) of bats found at all 3 wind facilities occurred during the fall season, as compared to spring, which most likely is the reason for the significance of the "season" variable. As discussed above, this is a common result in the literature (Arnett et al. 2008, Baerwald and Barclay 2011).

Although mortality was concentrated in the fall seasons, it was variable, with no bat carcasses being discovered 45%–68% of the fall search seasons, and relatively long periods of consecutive days (up to 22 days) when no mortalities were found. Furthermore, mortality was not spatially concentrated. We found no distinct spatial patterns amongst any of the 3 wind facilities. With rare exception, at least 1 bat carcass was found at nearly every searched turbine.

Contrary to other studies, we did not find that structural or habitat features were significant influences on bat mortality at any of the 3 wind facilities we investigated. For example, Brooks (2009) found that aquatic habitats were heavily used by bats, presumably for foraging and drinking. Limpens et al. (1989) discovered that bats used linear elements (i.e., roads, forested edges) on the landscape for commuting and navigation, and Krusic et al. (1996) recorded bats using trails for travel corridors. Even though agriculture dominated the land use and cover surrounding each wind facility, the landscape was scattered with wetlands of various sizes and linear elements from roads and forested edges. From our analysis it does not appear that the location of individual turbines or a wind facility as a whole relative to the proximity of bat habitat affects bat mortality.

It has been suggested that bats have excellent spatial memory and use landscape features for orientation and navigation (Baerwald and Barclay 2009, Johnson et al. 2011). The region that contained our 3 wind facilities was in relatively close proximity to major landscape features (i.e., Lakes Michigan and Winnebago) that may be used for short- or long-distance navigation as bats migrate through the area. Other significant features included the largest bat hibernacula in the midwestern US and a relatively large, contiguous block of forested habitat contained within the Kettle Moraine State Forest. Our analysis does not suggest that broad scale landscape features affect bat mortality.

The limitations with our study included the fact that we had only 1 spring and 1 fall season for 2 of the 3 wind facilities. Therefore, it is difficult to identify if CR, for example, would consistently record more bat mortalities than the other 2 wind facilities in our study. We also were not able to examine weather variables relative to bat mortality. Certain weather conditions, like low wind speeds, have been correlated with high bat mortality at wind facilities (Arnett et al. 2008). Weather conditions may have helped to explain some of the variation in numbers of bat mortalities we recorded at each of the wind facilities.

VI. Management Implications

Wind development companies are typically required to conduct pre- and post-construction studies specific to the wind energy facility being constructed and operated rather than rely on pre- and post-construction results from other wind energy projects due to different methodologies, regions, and habitats. Our study examined 3 wind farms that became operational in the same relative time frame, were constructed in similar land use and land cover within 2 counties of each other, and shared similar methodologies to investigate bat and bird mortality. Despite these similarities as well as similarities in the data between BSGF, CR, and FE, there were important differences. Specifically, the species composition of bat and bird carcasses as a result of turbine-caused mortality was different. Additional data would help determine if these results are consistent throughout the Midwest landscape as opposed to relying on results from past studies.

Mitigation techniques to minimize bat fatalities continue to be studied. Baerwald et al. (2009) and Arnett et al. (2011) discovered that curtailing turbine operation during the bat fall migration season or increasing the cut-in speeds for turbines reduced bat mortalities. Proactive siting of wind facilities to avoid known bat concentration areas and migratory routes is recommended as another mitigation option, although scant information is known about bat movement patterns and migration routes (Piorkowski et al. 2012). Our results do not suggest that strategically siting wind facilities would affect bat mortality. Our results reinforce other studies (Arnett et al. 2008) that bat mortality is concentrated in late summer/early fall. Our results suggest that a majority of the time bats were not being killed at the wind facilities we examined, and relatively long periods of time transpired between bat mortalities. We suggest further research be conducted to better understand and be able to predict bat mortalities, especially during peak mortality times in the fall, thereby refining curtailment as a cost-effective mitigation technique when necessary.

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